

Var C: Long-term photometric and spectral variability of an LBV in M33 ★ ★★,

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ABSTRACT

Aims. So far the highly unstable phase of luminous blue variables (LBVs) has not been understood well. It is still uncertain why and which massive stars enter this phase. Investigating the variabilities by looking for a possible regular or even (semi-)periodic behaviour could give a hint at the underlying mechanism for these variations and might answer the question of where these variabilities originate. Finding out more about the LBV phase also means understanding massive stars better in general, which have (e.g. by enriching the ISM with heavy elements, providing ionising radiation and kinetic energy) a strong and significant influence on the ISM, hence also on their host galaxy.

Methods. Photometric and spectroscopic data were taken for the LBV Var C in M33 to investigate its recent status. In addition, scanned historic plates, archival data, and data from the literature were gathered to trace Var C's behaviour in the past. Its long-term variability and periodicity was investigated.

Results. Our investigation of the variability indicates possible (semi-)periodic behaviour with a period of 42.3 years for Var C. That Var C's light curve covers a time span of more than 100 years means that more than two full periods of the cycle are visible. The critical historic maximum around 1905 is less strong but discernible even with the currently rare historic data. The semi-periodic and secular structure of the light curve is similar to the one of LMC R71. Both light curves hint at a new aspect in the evolution of LBVs.

Key words. galaxies: individual: M33 – stars: massive – stars: variables: S Doradus – stars: individual: Var C

1. Introduction

Luminous blue variables (LBVs) are stars in a short phase that lasts only several 10^4 years (e.g. Humphreys & Davidson 1994) towards the end of the evolution of some of the most massive and most luminous stars, between their main sequence and Wolf-Rayet (WR) phase. The initial masses of LBVs covered the range of 50 to 120 M_{\odot} . Newer models, however, that include rotation can also reproduce LBV progenitor stars with masses as low as 21 M_{\odot} (Meynet & Maeder 2005), matching the observations. LBVs have luminosities of about $10^6 L_{\odot}$.

An important property of LBVs – one that first defines them as LBVs – is their variability. LBVs show variability on different timescales (months, years, or decades) and with different amplitudes (a tenth of magnitudes up to > 2 mag) (Humphreys & Davidson 1994). A variability intrinsic to LBVs is the so-called S Dor variability. It occurs on a timescale of about 10-40 years during which the visual brightness rises 1-2 magnitudes while the bolometric brightness remains nearly constant. A more subtle distinction by van Genderen (2001) is the

classification of long (> 20 years, L-SD) and short (< 10 years, S-SD) S Dor variability, and the ex-/dormant class, that contains all LBVs that have not been active on a longer—not further defined—timescale.

These variations can be superimposed. The S Dor variability – also known as S Dor cycle or S Dor eruption – must be distinguished from so-called giant eruptions. While undergoing a giant eruption, LBVs can show even larger photometric variations of more than two magnitudes (Humphreys & Davidson 1994). A prominent example for them is the giant eruption of the LBV η Car in the 19th century. Giant eruptions of LBVs are also important because they might be mistaken for supernova explosions (Weis & Bomans 2005). So far it is unknown whether such giant eruptions can occur more than once in the same LBV. Therefore, a photometric monitoring and analysis is one of the – maybe the best – method(s) of actually pinpointing an LBV. In particular, to find and disentangle candidates in the L-SD and ex-/dormant classes (see above), establishing and analysing long-term light curves are essential. At the same time, this increases the chances of catching an LBV, for the first time, with a giant eruption and a known photometric post eruption history. Last but not least, long-term light curves can be checked for regular and periodic changes. For short-term S Dor LBVs, periodicities in the light curve have already been reported by van Genderen (2001). With only very few light curves spanning a large time span (e.g. 50 years and more), an analysis for the

* Based on observations collected at the Thüringer Landessternwarte (TLS) Tautenburg.

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long-term S Dor LBVs is still missing. With the addition of the light curve for Var C presented here and a recently reported long-term study of R71 (see Section 6), this kind of study starts to unfold.

LBVs not only show photometric variability, but also reveal different spectra depending on the state they are in. In their quiet – minimum light – phase, LBVs show the spectrum of a hot supergiant. Prominent are H, He, Fe II, and [Fe II] lines in emission, often also with P-Cygni profiles. At a phase of maximum light, the spectrum resembles that of a cool A – F type star (Humphreys & Davidson 1994). These changes in the spectral type can be associated with changes in the star’s apparent temperature. The corresponding shift of the Planck curve, hence of the colour of the star, is the mechanism behind the S Dor variability of an LBV.

LBVs have a high mass loss rate. During their quiet phase, this mass loss rate is of the order of $10^{-7} - 10^{-5} M_{\odot}/\text{yr}$, while during their S Dor eruption phase, this can reach up to $10^{-5} - 10^{-4} M_{\odot}/\text{yr}$ (Humphreys & Davidson 1994).

By sweeping up the slower older stellar wind of earlier phases and S Dor cycles, as well as through mass ejections during a giant eruption, small (< 5 pc, Weis 2011) circumstellar LBV nebulae are formed. These LBV nebulae contain CNO processed material from the star and are therefore rich in nitrogen and helium but low in oxygen and carbon (Maeder 1983).

To further determine the characteristics of LBVs it is necessary to find more of these stars. In Local Group galaxies, stars can be resolved spatially, and individual stellar parameters can be derived. The Local Group also provides different types of galaxies, hence different environments, and is therefore an ideal place to look for LBVs.

Periodicity on smaller timescales has already been known to occur in LBVs. The photometric variations in AG Car, an LBV in the Milky Way, where found by van Genderen (2001) to oscillate with periods of the order of one year ($P_0=371.4$ d; $P_1=305$ d or 475 d). Both periods appear superimposed. Shemmer et al. (2000) reported the M33 candidate LBV UIT301 (also named B416) to show a periodicity of 8.26 days.

The periodicities found so far belong to the short S Dor variability (S-SD). Only a few indications for periodicities of the long S Dor type (L-SD) have been reported (van Genderen et al. 1997). A likely reason for it is that for most LBVs, the time baseline of the light curve is too short. Even if data from past centuries are available, these are often only a few data points so that the resulting light curve is quite patchy. A recently reported exception is the LMC LBV R71 (Walborn et al. 2014).

The Local Group spiral galaxy M33 (classified as Scd) is located at a distance of approximately 840 kpc (distance modulus of 24.53 ± 0.11 mag, Scowcroft et al. 2009). The proximity and low inclination of M33 make it an excellent target for studying single stars. It also provides the possibility to study LBVs in an environment with a fairly low metallicity ($Z=0.008$).

Hubble & Sandage (1953) first noticed the variability of several massive stars, which include Var C in M33. Based on this publication, those stars were referred to as Hubble–Sandage variables. Finally together with the P Cyg- and S Dor-like variables, they were united under the term LBVs (Conti 1984).

With $\alpha_{2000}=1:33:35.14$ and $\delta_{2000}=30:36:00.55$, Var C is located only about $5'$ south-west of the centre of M33 (Figure 1). Figure 2 shows the H_{α} -image (upper panel) and the continuum-subtracted H_{α} -image (lower panel) of Var C and its surroundings. After comparing both images, Var C shows a bright H_{α} emission, while neighbouring stars do not.

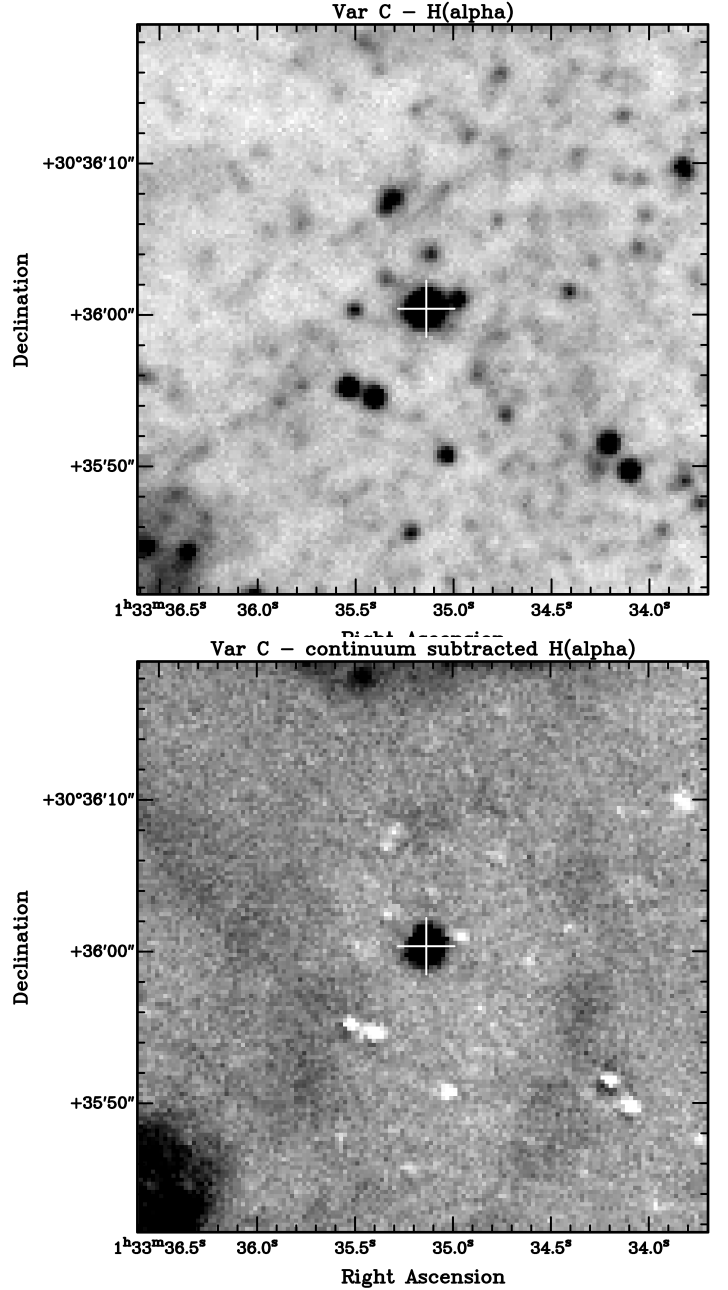


Fig. 2. H_{α} -image (upper panel) and continuum-subtracted H_{α} -image (H_{α} -R; lower panel) of Var C and its surroundings. Images were produced from NOAO LGGS data and have a size of about $150 \text{ pc} \times 150 \text{ pc}$. North is up and east is to the left.

In the continuum-subtracted H_{α} -image, Var C seems to be surrounded by a faint ring-nebular-like structure with a radius of approximately 50 pc, which would be consistent with the star’s main sequence bubble. Weaver et al. (1977) give a radius of approximately 30 pc for the size of such a bubble, depending on the density of the surrounding interstellar medium (ISM).

Since both photometric and spectral observations of Var C have been made numerous times in the past, this provides us with the rare chance to trace the behaviour of an LBV over a wide span of time. For Var C we compiled a light curve that has a significant length (more than 100 years) in combination with a reasonable coverage of data points. This gives the chance not only to look for long time variations, but also to check whether these variations might be periodic. Since the origin of the vari-

Table 1. Log of observations.

Date		Filter	Site
13, 31	Aug. 2002	B, V	WIYN
14	Sept. 2002	B, V	WIYN
10	Oct. 2002	B, V	WIYN
11	Nov. 2002	B, V	WIYN
7, 23	Jan. 2003	B, V	WIYN
19, 26	Sept. 2003	B, V	WIYN
20	Oct. 2003	B, V	WIYN
15	Nov. 2003	B, V	WIYN
27	Dec. 2003	B, V	WIYN
16	Jul. 2005	B, V	WIYN
8, 9, 10, 12, 13	Oct. 2005	V	COoSAI
28	Jan. 2006	B	TLS
27	Jul. 2006	B	CAHA
4	Sept. 2006	B	CAHA
2, 5, 8, 10, 11, 13, 14	Oct. 2006	V	COoSAI
22	Oct. 2006	B	CAHA
2	Oct. 2007	B, V	COoSAI
3	Oct. 2007	V	COoSAI
11	Oct. 2007	B, V	COoSAI
14	Oct. 2007	B, V	TLS
15, 17	Oct. 2007	B, V	COoSAI
6	Jan. 2008	B, V	TLS
2	Oct. 2008	B, V	TLS
22	Dec. 2008	B, V	TLS
20	Jan. 2009	B, V	TLS
28	Feb. 2009	B, V	TLS
19	Sept. 2009	B	TLS
19	Oct. 2009	B	TLS
21, 22	Oct. 2009	B, V	TLS
5, 8	Nov. 2009	B, V	COoSAI
20	Feb. 2010	B, V	TLS
25	Feb. 2011	B	TLS
2	Mar. 2011	V	TLS
31	Aug. 2011	B	TLS
2	Sept. 2011	B	TLS
4	Sept. 2011	V	TLS
29	Sept. 2011	B	TLS
30	Sept. 2011	V	TLS
1, 3	Oct. 2011	B, V	TLS

abilities in LBVs is not known yet, finding a periodic behaviour could give a hint of the underlying mechanism for these variations.

2. Observations and data analysis

2.1. CCD Imaging

2.1.1. Observations from TLS

Observations with the 2m-telescope of the *Thüringer Landessternwarte* (TLS) Tautenburg in its Schmidt mode were taken during several runs between January 2006 and October 2011. The SITE detector was used with 2048×2048 pixels and an image scale of 1''23/pixel (FOV: 42'×42') in combination with broadband Johnson B, V, R filters or a narrowband (100Å) H α filter, respectively. A standard data reduction (bias correction, flatfielding) was carried out using IRAF and a photometric analysis was performed using CCDCAP (Mighell 1998).

2.1.2. Observations from CAHA

We derived photometric data during our M33 survey using the *Calar Alto Faint Object Spectrograph* (CAFOS) in its imaging mode at the 2.2m-telescope at the Calar Alto Observatory (*Centro Astronómico Hispano Alemán* (CAHA)). The data were recorded from July to October 2006 during three runs in service mode using CAFOS at the 2.2m-telescope. SITE-1d detector with 2048×2048 pixels, an image scale of 0''.53/pixel and a field of view of about 16'×16' was used. Images were taken in B and R filters. Basic data reduction was performed using IRAF. Subsequently, photometry was carried out using DOLPHOT (Dolphin 2000).

2.1.3. Observations from COoSAI

CCD observations at the *Crimean Observatory of Sternberg Astronomical Institute* (COoSAI) were made during 19 nights between October 2005 and October 2009. The 60cm reflector (C60) equipped with an Apogee AP47 camera and a wide-field telescope (the 50cm Maksutov camera-AZT-5) equipped with a Pictor camera were used. The typical uncertainty of our estimates is 0.1 mag (0.2-0.5 mag for stars fainter than 17 mag).

2.1.4. Observations from WIYN

Between August 2002 and July 2005, observations were made with the 3.5m-telescope at the *Wisconsin-Indiana-Yale-NOAO* (WIYN) Observatory. The Mini-Mosaic imager consisting of two CCDs with 4096×2048 pixels, a field of view of 9'6×9'6, and an effective sampling of 0''.28/pixel was used. A basic data reduction was performed using IRAF. PSF photometry was carried out using IRAF/DAOPHOT. A detailed description of the analysis method is given in Pellerin & Macri (2011).

2.1.5. Observations from the DIRECT project

Unpublished data from the DIRECT project taken between September 1996 and November 1998 were used to supplement the light curve. A description of the data and the analysis method can be found in Pellerin & Macri (2011). The DIRECT project (e.g. Kaluzny et al. 1998) was carried out to determine the direct distances to M31 and M33 using Cepheids and detached eclipsing binaries. CCD observations with 1-m class telescopes in BVI filters started in 1996.

2.1.6. Archival data from NOAO

Archival data from the *National Optical Astronomy Observatory Local Group Galaxies Survey* (NOAO LGGS) (Massey et al. 2001) taken with the 4m-telescope at *Kitt Peak National Observatory* (KPNO) in October 2000 and September 2001 were also used to perform photometric analysis. These images consisted of 8192×8192 pixels and had an image scale of 0''.271/pixel (FOV: 36'×36').

A basic data reduction (bias correction, flat fielding, etc.) was already done by Massey et al. (2002), but photometry was not yet available when we started our project. We therefore performed PSF photometry using IRAF/DAOPHOT. The comparison with Massey et al. (2006) revealed only a small photometric offset of a tenth of a magnitude, which was corrected.

2.2. Photographic plate scans from TLS

Our photometric data set was supplemented by archival photographic plates of M33 taken between August 1963 and December 1996 with the Tautenburg Schmidt telescope (free aperture 1.34m, focal length 4m). A single Tautenburg plate covers an unvignetted field of 3.3×3.3 with a plate scale of $51''4$ per mm. We made use of 77 B plates, all of which had been digitised with the Tautenburg Plate Scanner (Brunzendorf & Meusinger 1999). The digital images have a pixel size of $0''.5 \times 0''.5$.

Data was reduced in an analogous way to the method applied by Henze et al. (2008) for analysing digitised photographic plates of M31 taken with the same telescope. We used the Source Extractor package (Bertin & Arnouts 1996) for object detection, background correction, and relative photometry. The photometric calibration was done using the M33 part of the Local Group Galaxies Survey (LGGS, Massey et al. 2006). A detailed description of the analysis method is given in Henze et al. (2008).

2.3. Heidelberg Digitized Astronomical Plates

We used the *Heidelberg Digitized Astronomical Plates* (HDAP) to obtain additional datapoints for the sparsely sampled era at the beginning of the 20th century. Twelve photographic plates of M33 were taken with the 72cm Walz-Reflector between 1908 and 1922. No detailed or specific information on the spectral sensitivity of the emulsions that were used could be derived from the observers' notebook, except for one case ("blue sensitive"). We therefore treated all plates as blue-sensitive "normal" plates and calibrated the magnitudes into B band. We measured the brightness of Var C to fill the sparsely populated light curve for those epochs. The large spread in the quality of the plates prevented a consistent linearisation for this dataset. Therefore, magnitudes were derived using the classical Argelander method (Nijland 1901).

2.4. Historical data taken from literature

To trace the behaviour of Var C in the past, a light curve was created using data from both the literature and the archive. Since the historical data were either photographic magnitudes (m_{pg}) or B magnitudes, we compiled a light curve in B. We calculated m_{pg} into Johnson B magnitudes using the following conversion given in Meusinger et al. (2010):

$$B = m_{pg} + 0.1. \quad (1)$$

B magnitudes were calculated for data points taken from Hubble & Sandage (1953), Sharov (1973), Rosino & Bianchini (1973), Lovas & Zsoldos (1988), and Sharov (1990).

In case no tabulated data existed, m_{pg} data points were extracted from given light curves using DEXTER (Demleitner et al. 2001). Errors in time and magnitude are mainly due to uncertainties from extracting the data. A maximum error was assumed to be half the size of the data point symbol in the light curve plot. This gave an error of $JD \pm 36$ days and $m_{pg} \pm 0.051$ mag for data values taken from Hubble & Sandage (1953), $JD \pm 18$ days and $m_{pg} \pm 0.023$ mag for values from Rosino & Bianchini (1973), and $JD \pm 220$ days and $B \pm 0.094$ mag for values from Zharova & Sholukhova (2004).

Magnitudes derived from photographic plates or photometers already given in B magnitudes were taken from van den Bergh et al. (1975), Humphreys (1978),

Humphreys & Warner (1978), Humphreys et al. (1984), Humphreys et al. (1988), and Kurtev et al. (1999). Further B CCD-photometry values came from Wilson (1991), Massey et al. (1995), Szeifert et al. (1996), Mochejska et al. (2001), Viotti et al. (2006), Humphreys et al. (2013b), and Valeev et al. (2013).

All B data values are collected in Tables 3 and 4, given in the appendix.

Additional V band data used in Figure 8 are from Spiller (1992), Macri et al. (2001), and Shporer & Mazeh (2006).

For completeness, in the following we list published values for Var C, which had no observation times given. Therefore, these values could not be included in the light curves. The catalogue from Ivanov et al. (1993) lists Var C as star IFM_B 600. Values of $V=15.20$ mag, $B-V=0.30$ mag ($B=15.50$ mag), and $U-B=-0.40$ mag ($U=15.10$ mag) are given. Var C is listed as v267 by Fabrika & Sholukhova (1995) with values of $V=16.70$ mag and $B-V=0.30$ mag ($B=17.00$ mag).

2.5. Spectral observations from SAO RAS

Two spectra were taken on 13 November 2004 and 22 October 2008 with the 6m-telescope at the *Special Astrophysical Observatory of the Russian Academy of Sciences* (SAO RAS). The *Multi-Pupil Fiber Spectrograph* (MPFS) (Sholukhova et al. 2007) and the *Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations* (SCORPIO) (Afanasiev & Moiseev 2005) were used respectively.

3. Light curve of Var C

A light curve of Var C between 1899 and 2013 containing values from the literature, photometry done on archival data, and our observations is presented in Figure 3. The corresponding data values are listed in Tables 3 and 4.

The earliest four data points found in the literature spread over almost 20 years and vary over one magnitude. Low data coverage during that time prevented us from reconstructing the stars photometric behaviour on short timescales. The overall trend indicates a peak around 1905 and, in total, a decline until 1915.

Additional plate data from HDAP (Figure 3; filled red diamonds) further confirm the indication from the Mount Wilson data (Hubble & Sandage (1953); black dots) of a broad maximum between 1900 and 1915. The lack of data around 1905 and before 1899 prevents us from putting stronger constraints on the maximum.

More regular time coverage of Var C is available starting in 1918 when the star showed a brightness of approximately 17.5 mag in B consistently in the Mount Wilson and HADP data. Until the mid 1930s, the star remained at almost constant luminosity apart from some smaller variations of less than half a magnitude. Subsequently, the luminosity of Var C started to increase over more than ten years until it reached its first established prominent maximum. With a gap in the data coverage present between 1941 and 1945, the slope of the light curve towards the maximum is not sampled very well. This maximum around 1947 with a maximum brightness in B of about 15.4 mag lasted at least three years. The luminosity started to decline around 1950. The sparse data coverage also makes it hard to determine the minimum value with good accuracy, which is probably almost as faint as before rising.

Minor increases of up to one magnitude are seen around 1957 and 1963. Especially the later rise and decrease is very

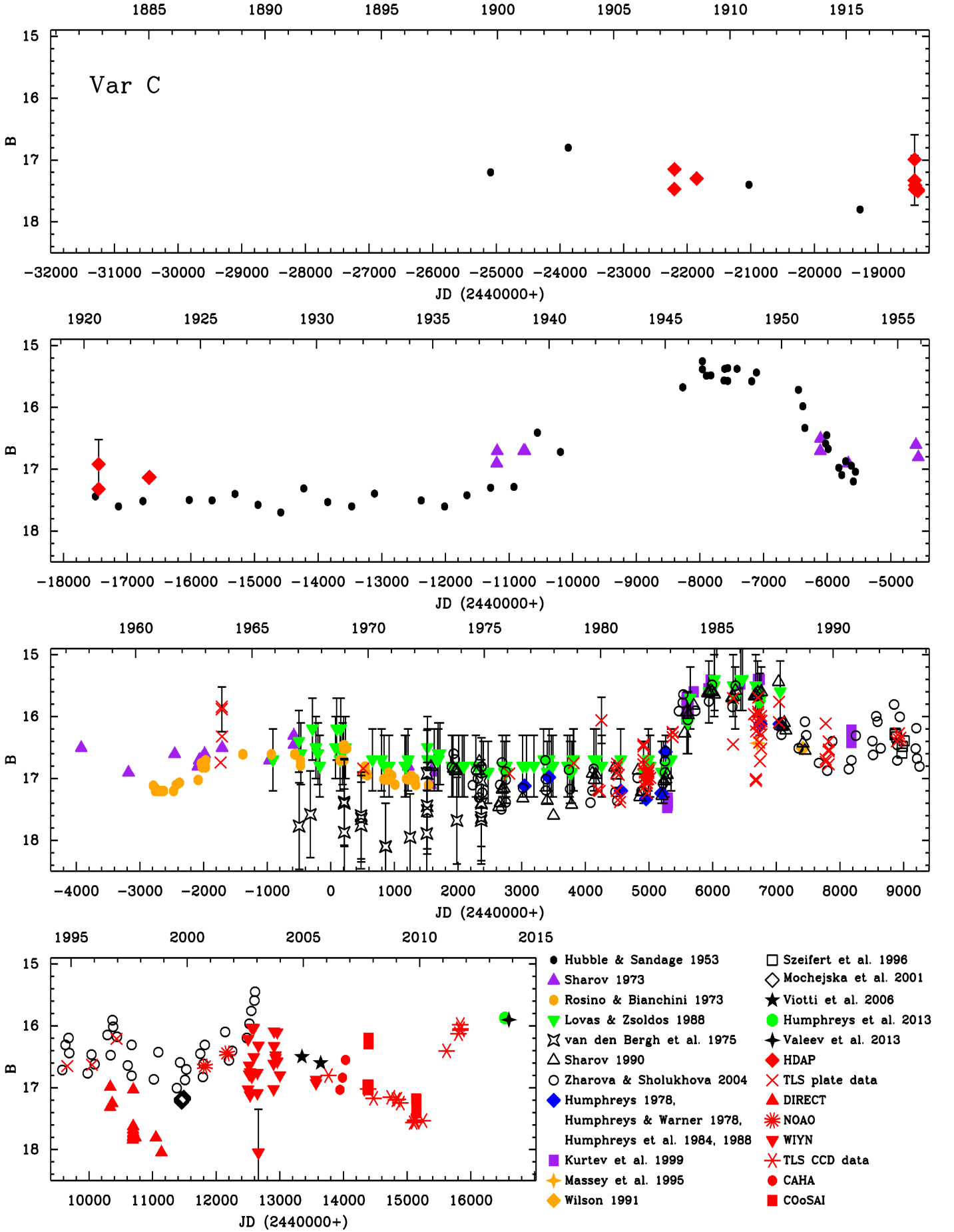


Fig. 3. B light curve of Var C between 1899 and 2013. For reasons of clarity and readability error bars are only given for data with uncertainties of more than 0.4 mag. The data values are listed in Table 4. Where available, also magnitude errors are given there.

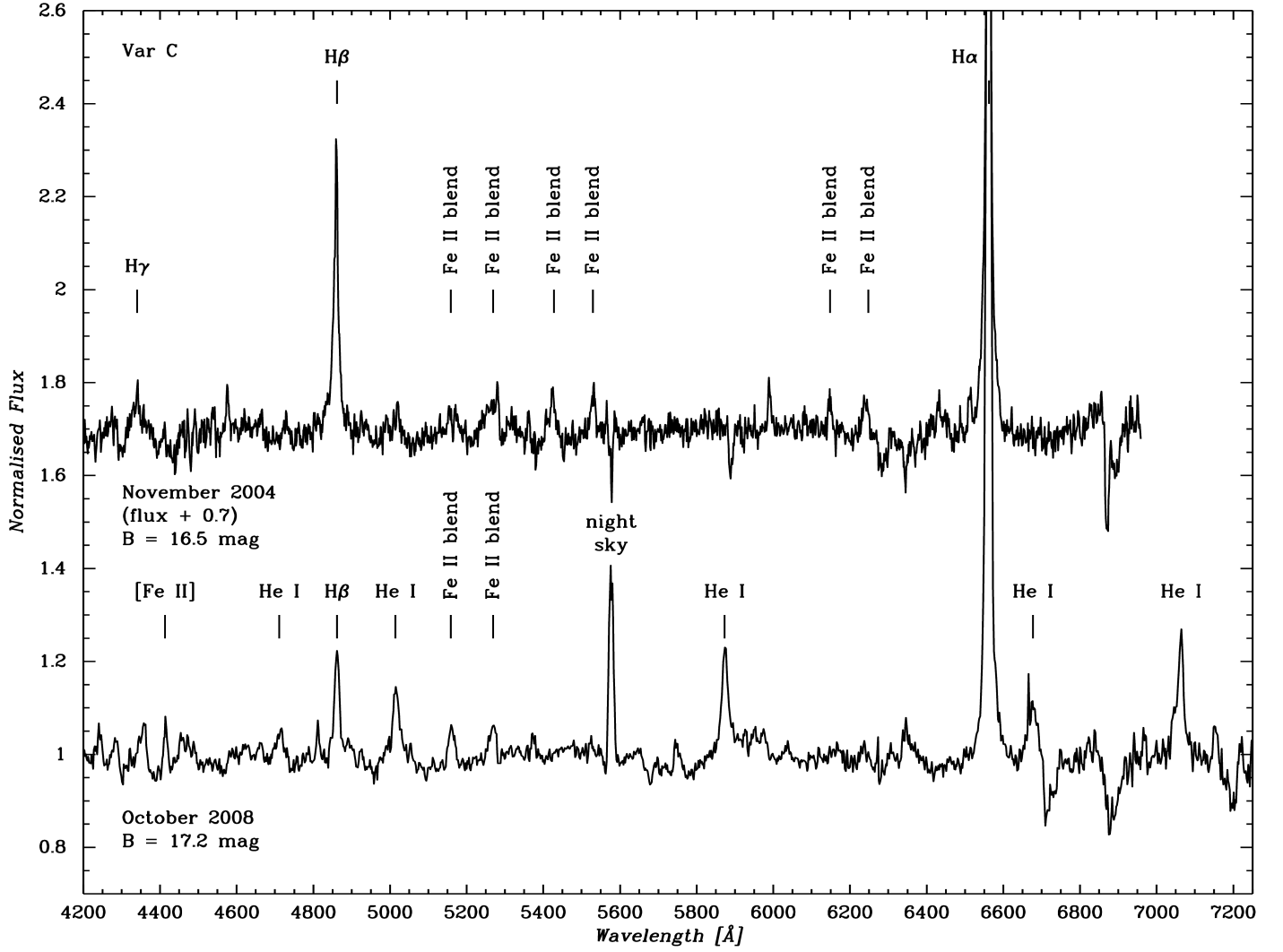


Fig. 4. SAO RAS spectra of Var C taken on 13 November 2004 (upper spectrum) and 22 October 2008 (lower spectrum).

narrow with almost one magnitude in less than one month. A broader and less luminous minor maximum around 1967 can be assumed.

With the exception of smaller variations between 1970 and 1982, Var C stayed constant at a B brightness of ≈ 17 mag. Since most of the values at this phase are photographic or photoelectric measurements, there might be a zeropoint or colourterm offset. When taking this into account, it is probably more significant for judging the variability to only look at variations within each set of data values separately. Since all data of one data set were very likely processed in the same way, variations in the data values can be trusted to be real.

The next prominent maximum occurred around 1986 where the luminosity again rose to about 15.4 mag for about four years. The rapid rise – in particular in the R band (compare Figure 1 from Humphreys et al. (1988)) – was followed by a steep decline in luminosity, which occurred at the end of 1986. It can be seen well in the TLS plate data (fig. 3 red crosses) but is also present in the data by Humphreys et al. (1988) (fig. 3 blue diamonds) and Massey et al. (1995) (fig. 3 yellow four-ray star). Within 120 days, variations of about one magnitude are seen.

Around 1990 the luminosity in B of Var C was almost back to a value before the rise. During the next 20 years minor and/or steeper increases and declines took place, namely in 1992, 1996,

end of 2002, and 2007. The maximum around 2002/2003 was nearly as bright as the two previous prominent maxima, but a much steeper increase and a decrease is present in this one.

In September 2009 the luminosity in B was 17.56 mag. It brightened in October 2011 and reached a new maximum value of 15.87 mag on 1 September 2013 (Humphreys et al. 2013b) and has stayed at this new maximum light level ever since. That Var C stayed at maximum light during this time and did not pass through two close and short maxima, is even more evident in the V light curve, that has additional measurements (see Figure 8 middle panel).

4. Spectra of Var C

The first spectra of Var C have already been reported in Hubble & Sandage (1953). Spectra were taken between November 1946 and November 1951. The first two spectra were taken in November 1946 and in August 1947, when Var C was in a phase of maximum light (see Figure 3). The spectra show Ca II K ($\lambda 3933$) and Ca II H ($\lambda 3968$) in absorption. Both lines have nearly equal strengths. According to Hubble & Sandage (1953), this is “[...] indicating that the spectral class is at least later than F0.” In the first of these two spectra, H γ and H δ are weakly present in absorption, while the second one shows no

hydrogen lines. The next spectra were taken during descending light. In 1949 the spectra showed faint H_β emission but no Ca II K or Ca II H lines were visible. The spectra taken from August to October 1951 show a much stronger H_β line and an H_γ line, both in emission. Ca II K and Ca II H were seen in absorption. In November 1951, H_β and H_γ were still seen in emission, but no Ca II K and Ca II H lines were visible.

Based on their spectrum obtained in September 1973, Sharov et al. (1975) reported that Var C was displaying a bright H_α emission. Humphreys (1975) recorded two spectra taken in October and November 1974 that showed several hydrogen, He I , Fe II , and $[\text{Fe II}]$ lines in emission, as well as Ca II K in absorption. She stated that Var C is an η Carina-like object.

Humphreys (1978) compared a spectrum taken two years later in August 1976 with the two spectra taken previously. The hydrogen and He I emission lines had become weaker and some of the Fe II and $[\text{Fe II}]$ lines were no longer seen.

The spectra taken in November 1983 by Kenyon & Gallagher (1985) showed H_α , H_γ , and numerous Fe II lines in emission. All these lines showed pronounced P-Cygni profiles. Strong $\text{Mg II } \lambda 4481$ was seen in absorption. Kenyon & Gallagher (1985) suggested a temperature for Var C at that time of only slightly less than <10000 K.

Several optical spectra of Var C taken between November 1985 and September 1987, as well as one UV spectrum (August 1986), were presented in Humphreys et al. (1988). The spectra of Var C taken in 1985 – corresponding to a maximum phase of Var C – showed only H_α and H_β in emission. Several strong lines of ionised metals including Fe II were seen in absorption. Humphreys et al. (1988) stated that the spectrum resembles that of an early F-type supergiant (F0Ia–F5Ia). They estimated a surface temperature of ≈ 7500 K. The optical spectra taken in 1986 showed weaker metallic lines, indicating—together with its ratio of the Ca II K and Ca II H lines—a higher surface temperature of up to 9000 K and a spectral type of about A2 to A3 (Humphreys et al. 1988).

The UV spectrum showed no emission lines, but Fe II lines in absorption underlined the estimation of Var C being an A-type star at that time. In the high-resolution spectra taken in September 1987 Fe II and other metallic lines were seen in absorption, as well as several Fe II -lines in emission. H_α , H_β , and H_γ showed P-Cygni profiles.

Szeifert et al. (1996) presented optical spectra taken in November 1991, October 1992, and December 1992. An additional UV spectrum was taken in July 1992. The 1992 spectra were described to show weak He I lines in absorption corresponding to a temperature >10000 K at that time. A comparison made between the spectra from 1987 (presented in Humphreys et al. 1988), 1991, and 1992 shows that the hydrogen and Fe II emission lines were getting stronger. Both optical and UV spectra were described to be consistent with a post-maximum phase of Var C.

A spectrum taken in December 1993 (Massey et al. (1995), Massey et al. (1996), and Massey et al. (2007)) showed pronounced hydrogen lines in emission and several Fe II and $[\text{Fe II}]$ in emission. He I is weakly seen. Spectra taken in December 2004 and January 2005 by Viotti et al. (2006) showed strong hydrogen lines in emission. Several Fe II and $[\text{Fe II}]$ lines were seen in emission. A spectral type of B[e] was given.

Clark et al. (2012) reported on two spectra taken on 30 November 2003 and 29 September through 2 October 2010. The first one showed H_β in emission and numerous metallic absorption lines. The spectrum was compared to a spectrum of the F0-F5Ia⁺ hypergiant B324. The spectrum taken in 2010 showed

H_α , H_β , and H_γ in emission. Several He I lines were also seen in emission, as was Fe II . The emission lines showed P-Cygni profiles. Var C became hotter from 2003 to 2010. As seen from the light curve, the luminosity of Var C decreased during this time.

Two SAO RAS spectra taken on 13 November 2004 and 22 October 2008 are presented in Figure 4. The spectrum recorded in November 2004 shows H_α , H_β , and H_γ in emission. Several weak Fe II lines are present in emission. In the spectrum from October 2008, H_α and H_β are seen in emission. Several He I and some Fe II lines are very present in emission. Comparing this development with the slope of the light curve shows that Var C faded between the end of 2004 and the end of 2008 of about 0.7 mag. This is consistent with the spectra and indicates that the star is entering a hot phase.

A spectrum of Var C taken 3 October 2010 (Humphreys et al. 2014) shows Balmer lines in emission. Several He I and numerous Fe II and $[\text{Fe II}]$ lines are also seen in emission. Pronounced P-Cygni profiles are present in the spectrum. With respect to the light curve, the spectrum was taken after a minimum, with Var C increasing its luminosity, but still representing a hot star.

A low-resolution spectrum taken on 18 September 2013 by Viotti et al. (2013) is described to show hydrogen lines in emission.

Two spectra taken on 5 October 2013 and 1-2 November 2013 were reported by Valeev et al. (2013). The spectra were described to show Fe II lines in emission, as well as $[\text{Fe II}]$ and strong hydrogen lines. He I was seen very weakly in absorption. P-Cygni profiles were present in the hydrogen lines and the majority of the Fe II lines.

Another spectrum taken on 7 October 2013 by Humphreys et al. (2014) showed much weaker hydrogen lines in emission, Ca II and Mg II in absorption, and Fe II in emission with P-Cygni profiles. The spectrum is classified as late A-type. This spectral type was still confirmed with an LBT IR spectrum taken January 2014.

Table 2 summarises the optical spectral observations of Var C¹ observing the spectrum reported by Burggraf et al. (2011) taken in September 2007 was not that of Var C, but of a different star. Where not already given in the literature, a spectral type has been estimated based upon the description of the spectrum in the literature. The criteria for classifications were derived from spectral descriptions given by Jaschek & Jaschek (1987).

5. Discussion

5.1. Periodicity

While several semi-periodic structures are known to exist in the light curves of LBVs on timescales of about ten years, the periods are less stable than in Cepheids (van Genderen 2001), for example. The extremely long light curve of Var C that we established manifests an excellent unique data set to make a reliable analysis for even long-term trends and periods. A first inspection of the light curve of Var C reveals two pronounced maxima. The first maximum occurred around 1947 and a second one around 1986. To investigate the long scale variability in B of Var C, we analysed the periodicity using a Fourier analysis performed with Period04 (Lenz & Breger 2005). Data values from van den Bergh et al. (1975) were excluded because of the relatively large magnitude uncertainties of 0.7 mag, as was one data point from WIYN for the same reason. The B data values were

¹ Based on a misidentification during service,

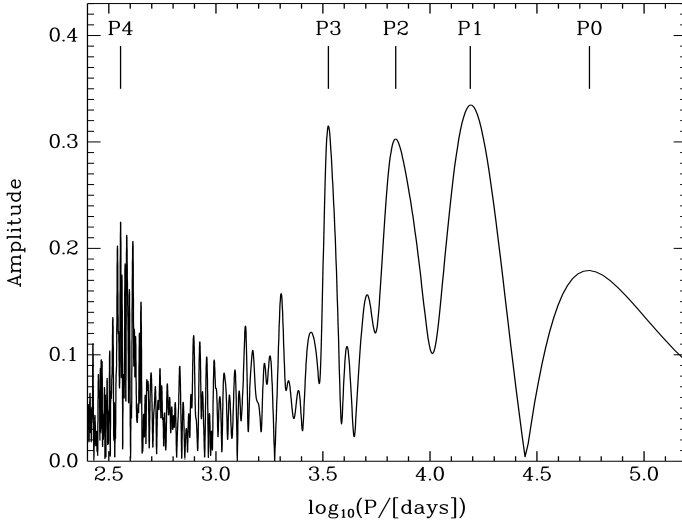


Fig. 5. Power spectrum derived from the B magnitude values presented in the upper panel of Figure 7. The highest peak (P1) corresponds to a period of 42.3 years. The values for the other peaks are given in Table 5.

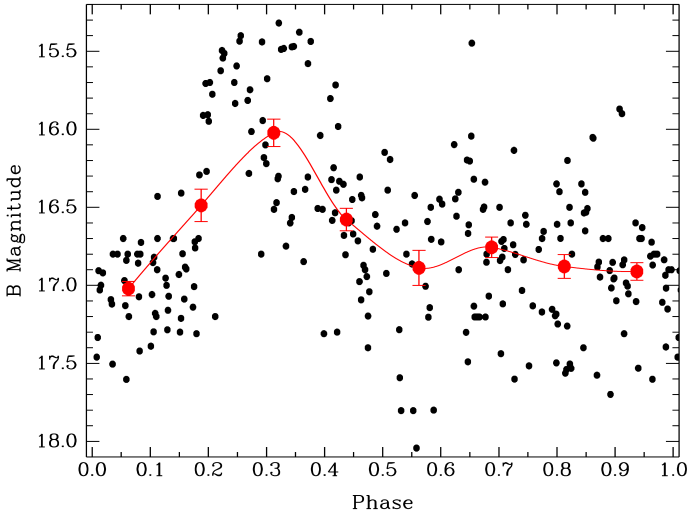


Fig. 6. Phase diagram using a frequency of $\nu = 6.477 \times 10^{-5}$ 1/d ($P_1 \approx 42.3$ years). The data has been binned (red dots) and the binned data fitted with an akima spline (red line). A zero point offset in time of 3000 days was applied.

Table 5. Peak values corresponding to Figure 5.

Peak	$\log_{10}(P/[d])$	Period P [years]	Frequency ν [1/d]	Amplitude
P0	4.745	152.2	1.799×10^{-5}	0.179
P1	4.189	42.3	6.477×10^{-5}	0.335
P2	3.841	19.0	1.444×10^{-4}	0.303
P3	3.526	9.2	2.980×10^{-4}	0.315
P4	2.555	1	2.786×10^{-3}	0.225

averaged by month in order to avoid being sensitive to small scale variations (below a month). A light curve of these averaged data is presented in Figure 7 (upper panel).

Figure 5 shows the power spectrum derived from the B data values. A bright peak is seen at $P_1 = 15440$ days = 42.3 years. Two more peaks are present at $P_2 = 6926$ days = 19.0 years and $P_3 = 3356$ days = 9.2 years. The peaks around P4 corresponding

to a period of approximately one year are most probably due to the sampling of the data. The very broad and low amplitude peak (P0) with the highest period is due to the apparent overall increase in the luminosity. Such a secular trend of brightening is also seen in the light curve of other LBVs like η Car. Table 5 lists the parameters of the main peaks labelled in Figure 5.

As seen from Table 5 periods, P1 and P2 are roughly multiples of period P3. The amplitudes of P1, P2, and P3 are also in the same order of magnitude. This could mean that the 40-year period is not real, which would then favour the twenty- or ten-year period.

To gain a better understanding of the structures found in the power spectrum, synthetic light curves were produced. Therefore, synthetic data modelling the main features of Var C's light curve were generated. Subsequently, Period04 was used on these data.

One of these synthetic light curves was generated with one data point per month at only six months per year, while no data points were set the other half of the year. This was done to reproduce that M33 is only observable during roughly half a year each year from the northern hemisphere. Using this setup, we were able to reproduce the broad bump consisting of several peaks around P4. When adding data points for the other six months, this peaks vanish. This indicates that the peak around P4 is indeed produced by the sampling of the data.

As another test, data points were added to the light curve of Var C by averaging neighbouring data points and adding the averaged value as a new data point in between them. This method was applied twice, so that a light curve with two times and another with four times the original number of data points were created. Both times Period04 found the same peaks (P1, P2, P3) with P1 having the highest amplitude, even though this still does not necessarily mean that the 40-year period is real.

The phase diagram corresponding to the maximum peak at a frequency of $\nu = 6.477 \times 10^{-5}$ per day (corresponding to period $P_1 = 15440$ days = 42.3 years) is given in Figure 6. The data has been binned into eight bins and these binned data has been fitted with an akima spline. A zero point offset in time of 3000 days was applied.

At least one prominent maximum is seen in the phase diagram. A second, smaller maximum at approximately half of the period might be assumed, but data scattering is much larger and renders it quite uncertain. This minor maximum is represented in Figure 5 by peak P1. It still might be that the period is only approximately 18-20 years with the maximum amplitude not always equally strong. Another interpretation would be that the period is ≈ 40 years with a major maximum and a minor maximum. Assuming the last major maximum was around 1986, the next strong maximum phase of Var C should occur around 2028 ± 3 . Nevertheless, (semi-)periodic behaviour on large time scales is seen in the light curve.

Some uncertainties arise from the fact that the data are from various telescopes and that transformations had to be made between different magnitude systems (m_{pg} , B). Assuming all data of one dataset have been processed in the same way, variations within such a dataset are more significant and give information about variability on smaller scales.

van Genderen (2001) found two frequencies (both roughly a year; $P_0 = 371.4$ days; $P_1 = 305$ days or 475 days) present in AG Car and superimposed on each other, resulting in a beat cycle of about 20 years. This looks similar to the 20-year period found in Var C's light curve (if assuming maxima of different amplitudes).

To check whether the periodicity in Var C's light curve on this long time scale might only be the result of a superposition of periodicities on smaller timescales, we also looked at the small variations of Var C. For this we used the data from the TLS plate scans to have a consistent data set. In addition we also used V band data from Macri et al. (2001) (images taken between September 1996 and October 1997) and Shporer & Mazeh (2006) (images taken between September 2000 and November 2003), covering a range of six years to search for periodicity.

Even though variabilities on smaller scales are obviously present in the light curve of Var C, no clear period around a year was found. Such small and intermediate scale periodicities are not even seen when looking only at separate datasets and at datasets with the highest data coverage. This means either that the data coverage is still not good enough to find these small scale periodicities or that the long-term periodicity found in Var C is not just a beat cycle resulting from the superposition of two or more frequencies, as in AG Car. This could mean that the periodicity of Var C is caused by a different mechanism than the long-term periodicity of AG Car.

Also no periodicity of days was found in Var C's light curve as in UIT301. Shemmer et al. (2000) reported the M33 LBV UIT301 (also named B416) to show a periodicity of 8.26 days. Even though Sholukhova et al. (2004) stated that this is the half of the orbital period and therefore light variations are due to a close interacting binary rather than to intrinsic variability in luminosity.

With an amplitude of approximately 1.5-2 mag for the major peak (and 0.5 mag for a minor peak – if present) and with an assumed length of 42 years, Var C can be classified as a strong-active S Dor member with a long S Dor (L-SD) cycle, as defined by van Genderen (2001). Comparing Var C's light curve with the light curves of other strong-active S Dor members given in van Genderen (2001), it is seen that, induced by sparse data coverage, the light curves are quite patchy. Time approximations for the L-SD durations indicate variabilities of decades, but no periodicity on these timescales can obviously be seen from the light curves. Most light curves show secular trends of de- or increasing light (e.g. R110). Some light curves show a single maximum (e.g. R116).

So far, regular-periodic-variations have not been known to be a common feature of LBVs. With the really long-term light curves, which have come up more recently, the first cases are being observed right now. Walborn et al. (2014) have reported on the LMC LBV R71 to show periodic variability on a timescale of about 40 years. More recently, the maxima have appeared more frequently and with a larger amplitude. This is similar to what was observed for the LBV Var B in M33 between 1930 and 1950, when Hubble & Sandage (1953) found three maxima with steadily increasing amplitudes.

Periodicity on a timescale of several decades is unusually long. Common mechanisms causing periodic light variations, such as the κ -mechanism, occur on much smaller timescales (days up to a few months). So far, no intrinsic stellar mechanism has been known to cause such long-term periodicity.

Recently, Koenigsberger et al. (2010) have found a 40-year cyclic variation in HD 5980, which is a multiple system consisting of a close binary (two Wolf-Rayet type stars orbiting each other with a period of 19.3 days) and a third O-type star component. The authors suggest that the observed slow variations due to changes in the radius were superimposed by strong and short-duration eruptions caused by the binary companion.

The similarity in the length of the periods found in Var C and HD 5980 might lead to the question of whether periodicity caused by interaction in a binary system is a general phenomenon and thus whether Var C might also consist of more than one component. So far, no hints of binarity have been reported for Var C. Also the available high-resolution spectra do not show evidence of any binarity.

Nevertheless, the photometric variations seen in HD 5980 and Var C appear to be quite different. The light curve of HD 5980 (see Koenigsberger et al. (2010) Figure 1) shows a sudden, short eruption after a slow brightening over several years. This peak is very steep and narrow. In contrast to that, Var C's first maximum shows a relatively slow rise and fall. The second maximum appears slightly steeper and narrower than the first one, but is still much broader than the peak seen in HD 5980. Both of Var C's maxima last at least a few years.

If Var C is indeed a single star, the similarity of the period might just be coincidental. In that case a completely different underlying mechanism has to be responsible for the (semi-)periodicity of Var C.

5.2. Temperature variations

By converting the photometrical colours of Var C into temperatures, a more physical interpretation can be made. For this we used Equations (4b) through (4e) from Parker & Garmany (1993) (see also references within).

For $(B - V)_0 < 0.0$ we used Equation (4b):

$$\log(T_{eff}) = 3.832 - 2.204(B - V)_0, \quad (2)$$

for $0.0 \leq (B - V)_0 < 0.2$ Equation (4c) was applied:

$$\log(T_{eff}) = 3.990 - 0.510(B - V)_0. \quad (3)$$

For $0.2 \leq (B - V)_0 < 0.5$ Equation (4d) was used,

$$\log(T_{eff}) = 3.960 - 0.344(B - V)_0, \quad (4)$$

and for $0.5 \leq (B - V)_0$ Equation (4e) was applied:

$$\log(T_{eff}) = 3.904 - 0.222(B - V)_0. \quad (5)$$

Parker & Garmany (1993) used these equations to calculate T_{eff} for stars with only photometric values available, hence for stars without any further spectral classification. According to them, Equation 2 is not valid for supergiants. Supergiants would be cooler (a few 1000 K, depending on the spectral type) than dwarfs of the same spectral type. Therefore, the estimated temperature would be too high, if the star was a supergiant.

Furthermore, the calculation of the temperature strongly depends on the assumed reddening of the star. Therefore, we determined the reddening from an U-B versus B-V colour-colour diagram using stars in the surrounding of Var C. Since Var C only has a few neighbouring stars, the determination of reddening is rendered somewhat uncertain. A mean value of 0.17 ± 0.07 was found. This is in good agreement with a reddening value for Var C from e.g. Viotti et al. (2006), who used $A_V = 0.6$, which equals $E(B-V) = 0.19$. We calculated temperatures for three different values of $E(B-V)$ of 0.10, 0.17, and 0.24.

Because of these uncertainties (validity of equations, reddening), these temperature calculations can only give a rough estimate. Nevertheless, they can be used to trace the general development of Var C's temperature curve. Table 7 lists the calculated temperatures. The calculations were done for colours derived from own photometries and from photometries from the

Table 7. Temperature estimations for Var C. Depending on the value of $(B-V)_0$ Equation 2, 3, 4, or 5 was used.

Date	B	V	E(B-V)=0.10		E(B-V)=0.17		E(B-V)=0.24		T/K	Observatory/ Reference
			(B-V) ₀	T/K	(B-V) ₀	T/K	(B-V) ₀	T/K		
Aug. 1963	16.74	16.36	0.28	7306	0.21	7723	0.14	8291	7800±500	TLS plate
Sept. 1963	16.01	15.75	0.16	8098	0.09	8792	0.02	9546	8800±700	TLS plate
Sept. 1976	17.12	17.17	-0.15	14541	-0.22	20743	-0.29	29591	21600±8000	1
Oct. 1977	16.98	16.98	-0.10	11282	-0.17	16095	-0.24	22959	16800±6200	2
Nov. 1980	17.20	17.21	-0.11	11870	-0.18	16932	-0.25	24155	17700±6500	3
Dec. 1981	17.33	17.23	0.00	9772	-0.07	9689	-0.14	13822	11100±2700	3
Aug. 1982	17.24	17.15	-0.01	7146	-0.08	10193	-0.15	14541	10600±3900	3
Oct. 1982	16.57	16.48	-0.01	7146	-0.08	10193	-0.15	14541	10600±3900	3
Sept./Oct. 1986	16.43	16.35	-0.02	7518	-0.09	10724	-0.16	15298	11200±4100	4
Nov. 1986	16.12	15.75	0.27	7364	0.20	7784	0.13	8389	7800±500	5
Sept. 1987	16.12	15.68	0.34	6967	0.27	7364	0.20	7784	7400±400	5
Aug./Oct. 1988	16.51	16.39	0.02	9546	-0.05	8754	-0.12	12488	10300±2200	6
Sept. 1992	16.30	16.11	0.09	8792	0.02	9546	-0.05	8754	9000±500	7
Dec. 1992	16.54	16.34	0.10	8690	0.03	9434	-0.04	8321	8800±600	7
Jan. 1993	16.39	16.21	0.08	8896	0.01	9658	-0.06	9210	9300±400	7
Sept. 1996	17.15	16.18	0.87	5139	0.80	5326	0.73	5520	5300±200	DIRECT
Oct. 1996	17.25	16.81	0.34	6967	0.27	7364	0.20	7784	7400±400	DIRECT
Aug. 1997	17.82	16.90	0.82	5272	0.75	5464	0.68	5663	5500±200	DIRECT
Sept. 1997	17.59	16.87	0.62	5839	0.55	6052	0.48	6236	6000±200	DIRECT
Oct. 1997	17.80	16.79	0.91	5035	0.84	5218	0.77	5408	5200±200	DIRECT
Aug. 1998	17.80	17.23	0.47	6285	0.40	6644	0.33	7022	6700±400	DIRECT
Nov. 1998	18.04	17.90	0.04	9324	-0.03	7909	-0.10	11282	9500±1800	DIRECT
Oct. 1999	17.20	17.08	0.02	9546	-0.05	8754	-0.12	12488	10300±2200	8
Nov. 1999	17.18	17.07	0.01	9658	-0.06	9210	-0.13	13138	10700±2500	8
Oct. 2000	16.65	16.53	0.02	9546	-0.05	8754	-0.12	12488	10300±2200	NOAO
Sept. 2001	16.45	16.33	0.02	9546	-0.05	8754	-0.12	12488	10300±2200	NOAO
Aug. 2002	16.67	15.83	0.74	5492	0.67	5692	0.60	5899	5700±200	WIYN
Sept. 2002	16.94	15.88	0.96	4908	0.89	5087	0.82	5272	5100±200	WIYN
Oct. 2002	16.43	15.86	0.47	6285	0.40	6644	0.33	7022	6700±400	WIYN
Nov. 2002	16.27	15.84	0.33	7022	0.26	7423	0.19	7818	7400±400	WIYN
Jan. 2003	17.05	15.81	1.14	4476	1.07	4639	1.00	4808	4600±200	WIYN
Sept. 2003	16.51	15.87	0.54	6083	0.47	6285	0.40	6644	6300±300	WIYN
Oct. 2003	16.50	15.56	0.84	5218	0.77	5408	0.70	5605	5400±200	WIYN
Nov. 2003	16.34	15.87	0.37	6803	0.30	7191	0.23	7601	7200±400	WIYN
Dec. 2003	16.80	15.74	0.96	4908	0.89	5087	0.82	5272	5100±200	WIYN
Dec. 2004	16.50	16.40	0.00	9772	-0.07	9689	-0.14	13822	11100±2700	9
Jul. 2005	16.90	16.26	0.54	6083	0.47	6285	0.40	6644	6300±300	WIYN
Sept. 2005	16.60	16.60	-0.10	11282	-0.17	16095	-0.24	22959	16800±6200	9
Oct. 2007	16.81	16.86	-0.15	14541	-0.22	20743	-0.29	29591	21600±8000	CoSAI
Oct. 2007	17.02	16.94	-0.02	7518	-0.09	10724	-0.16	15298	11200±4100	TLS CCD
Jan. 2008	17.17	17.08	-0.01	7146	-0.08	10193	-0.15	14541	10600±3900	TLS CCD
Oct. 2008	17.15	17.07	-0.02	7518	-0.09	10724	-0.16	15298	11200±4100	TLS CCD
Jan. 2009	17.19	17.10	-0.01	7146	-0.08	10193	-0.15	14541	10600±3900	TLS CCD
Feb. 2009	17.25	17.20	-0.05	8754	-0.12	12488	-0.19	17814	13000±4800	TLS CCD
Oct. 2009	17.53	17.47	-0.04	8321	-0.11	11870	-0.18	16932	12400±4600	TLS CCD
Nov. 2009	17.23	16.86	0.27	7364	0.20	7784	0.13	8389	7900±500	CoSAI
Feb. 2010	17.53	17.51	-0.08	10193	-0.15	14541	-0.22	20743	15200±5600	TLS CCD
Feb. 2011	16.40	16.21	0.09	8792	0.02	9546	-0.05	8754	9000±500	TLS CCD
Aug. 2011	16.13	15.81	0.22	7662	0.15	8194	0.08	8896	8300±600	TLS CCD
Sept. 2011	15.98	15.79	0.09	8792	0.02	9546	-0.05	8754	9000±500	TLS CCD
Oct. 2011	16.06	15.81	0.15	8194	0.08	8896	0.01	9658	8900±700	TLS CCD
Sept. 2013	15.87	15.66	0.11	8588	0.04	9324	-0.03	7909	8600±700	10
Nov. 2013	15.9	15.7	0.1	8690	0.03	9434	-0.04	8321	8800±600	11

References. (1) Humphreys (1978); (2) Humphreys & Warner (1978); (3) Humphreys et al. (1984); (4) Massey et al. (1995); (5) Humphreys et al. (1988); (6) Wilson (1991); (7) Szeifert et al. (1996); (8) Mochejska et al. (2001); (9) Viotti et al. (2006); (10) Humphreys et al. (2013b); (11) Valeev et al. (2013)

literature. The resulting temperature curve is given in Figure 7 (middle panel).

Figure 7 illustrates the connection between light variations and changes in temperature, hence in spectral type. The upper panel shows the B light curve of Var C. In contrast to the light curve presented in Figure 3, the B values here were averaged by

month. These are also the B values used for analysing the periodicity. The middle panel presents the corresponding temperatures. Literature values and temperature estimated from photometric values are plotted. Finally, the lower panel shows the spectral types of Var C at different times. Values are either taken

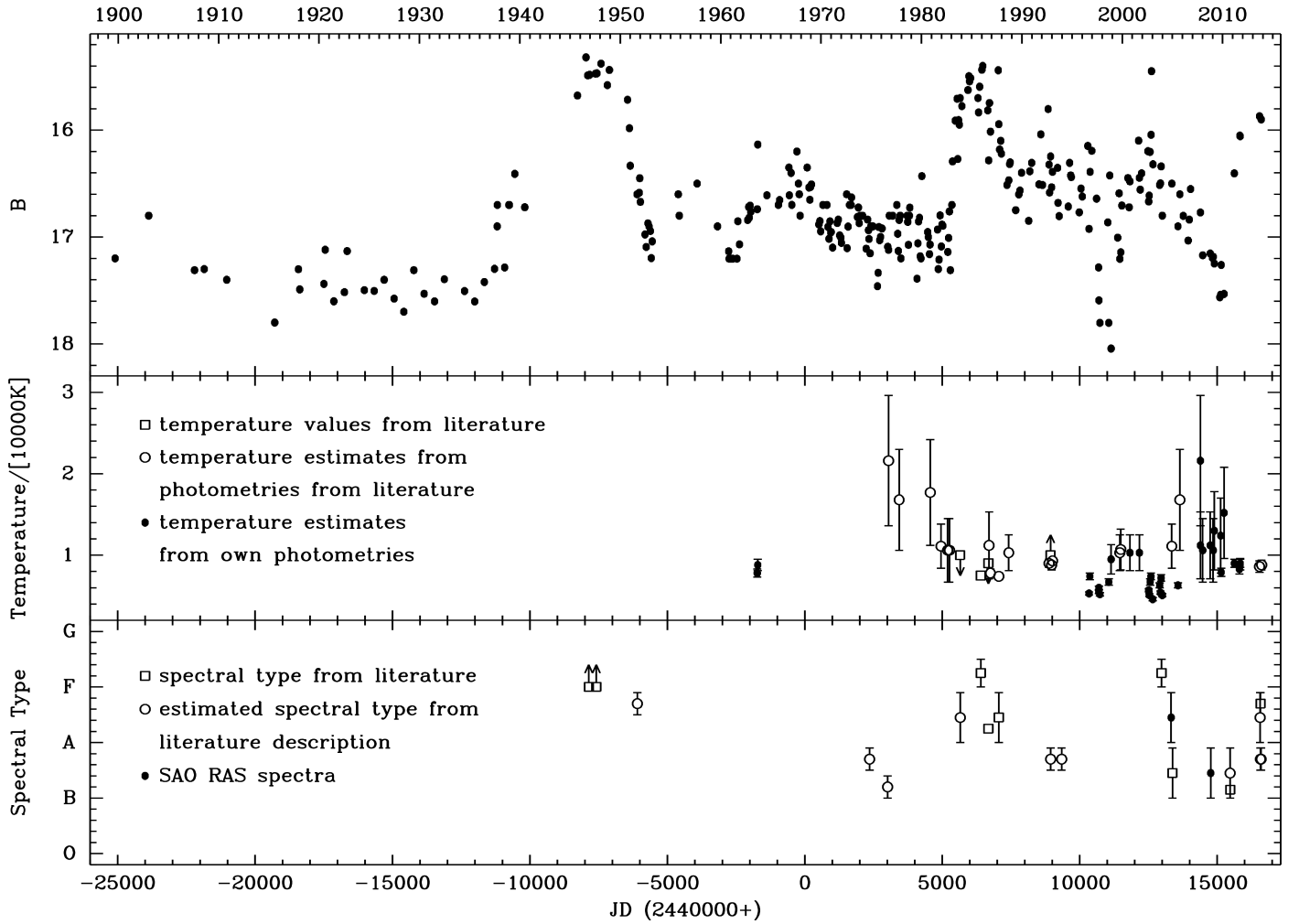


Fig. 7. B light curve of Var C (upper panel). In comparison to Figure 3, the B values here have been averaged by month. The corresponding temperatures and spectral types are given in the middle and lower panels, respectively.

directly from the literature or are estimated spectral types from the description of a spectrum in the literature (see also Table 2).

Even though the coverage with spectral data is quite patchy, it is seen that during maximum light, the star resembles an A- or F-type star. During phases of minimum light an O- or B-type star is seen. Since changes in the spectral type are caused by changes in the temperature, this trend is also seen in the temperature curve. For example, during the maximum around 1986, temperatures around 10000 K are seen, while temperatures above 16000 K are present just before this maximum. Also the decrease in luminosity between 2003 and 2010 is accompanied by a rise in the temperature curve, while lower temperatures are measured again in the beginning maximum after 2010.

Some additional V band data were available for Var C. Therefore, a V light curve is also presented in the middle panel of Figure 8. For a comparison, the B light curve is shown in the upper panel of the same figure. The corresponding B–V colour curve is given in the lower panel.

As for changes in the spectral type, changes in the colour (here B–V) also represent changes in the temperatures of a star. Lower B–V values indicate redder, hence cooler stars. As seen from Figure 8, the B–V colour curve also shows that Var C is redder and cooler when it is in maximum light.

All these described trends in the temperature and light variations – cooler when in minimum light and hotter while in maxi-

mum light – indicate S-Dor behaviour, the variability intrinsic to LBVs. A detailed SED fitting, however, is not possible because for most epochs, no multi-wavelength observations have been recorded.

6. Conclusions

We investigated the long-term photometric and spectral behaviour of the LBV Var C in M33. We classified Var C as a strong-active S Dor member with a long S Dor (L-SD) cycle. A long-term (semi-)periodicity with a period of 42.3 years is detected with the chance of the real period being 19.0 years or even 9.2 years. If a long-term periodicity of approximately 42 years is present in the B light curve of Var C, the next maximum light should occur around 2028 ± 3 . However, developments since 2010 have shown that Var C is already entering a phase of maximum light 15 years earlier, which is not consistent with the longest possible period, but is within the uncertainty that matching both the shorter periods.

Var C has been in maximum light for more than one year now (Humphreys et al. 2013b). Even though Var C is approximately 0.5 mag fainter than during the two prominent maxima in 1947 and 1986, the slope of the rise and the duration so far fits the previous two bright maxima, indicating a comparable eruptive state. Var C’s spectral, colour, and temperature curves, together

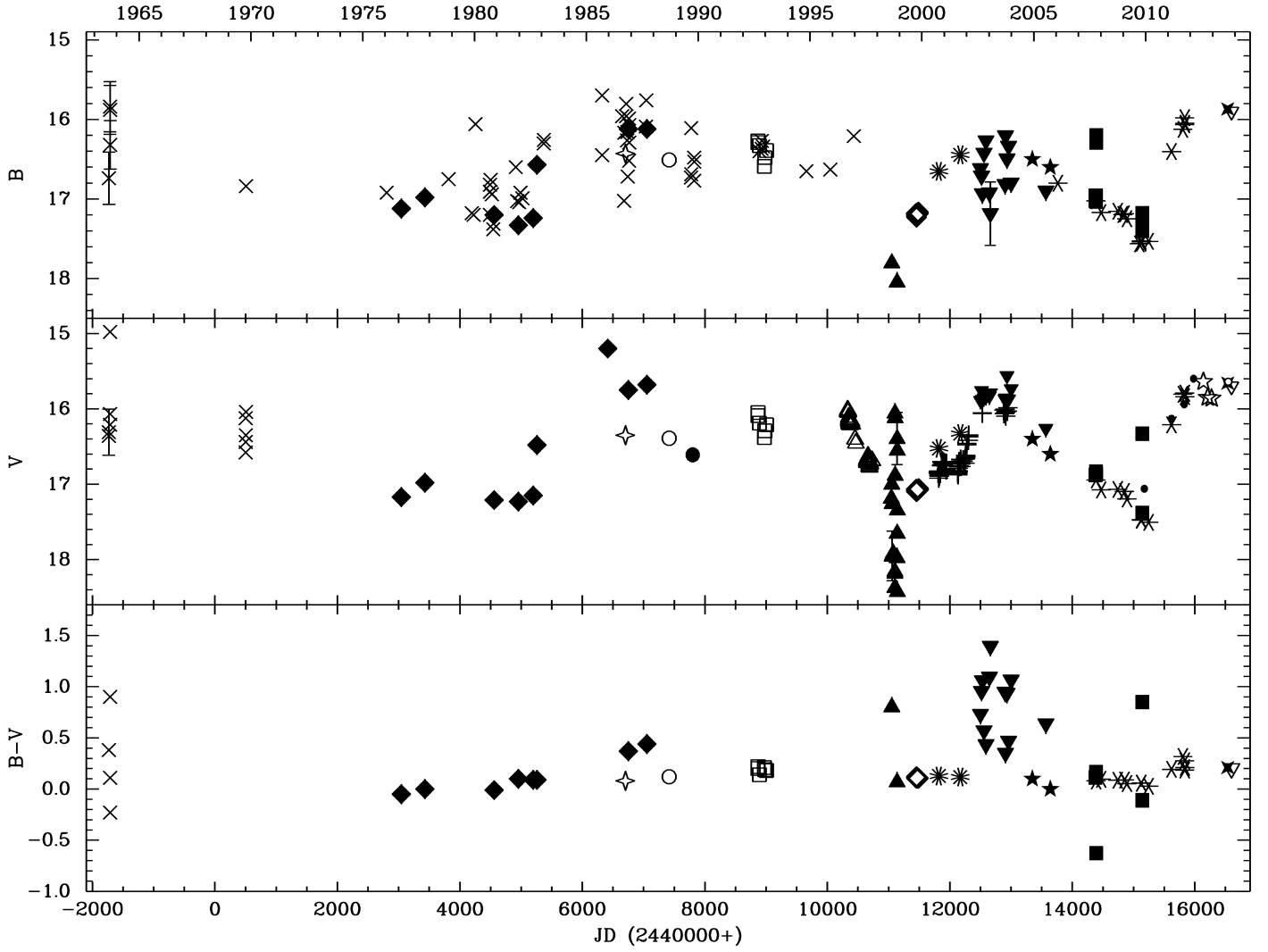


Fig. 8. B and V light curves and B–V colour curve of Var C. Crosses: TLS plate data; filled upwards triangles: DIRECT; stars: NOAO; filled downwards triangles: WIYN; stars with six rays: TLS CCD data; filled squares: COoSAI; filled diamonds: Humphreys (1978), Humphreys & Warner (1978), Humphreys et al. (1984), and Humphreys et al. (1988); open four-ray stars: Massey et al. (1995); open circles: Wilson (1991); filled circle: Spiller (1992); open squares: Szeifert et al. (1996); open upwards triangles: Macri et al. (2001); open diamonds: Mochejska et al. (2001); plus signs: Shporer & Mazeh (2006); filled five-ray stars: Viotti et al. (2006); filled small dots: Viotti et al. (2013); open small dot: Roberto Viotti, Franco Montagni (private communication); open five five-ray stars: John Martin (private communication); filled four-ray stars: Humphreys et al. (2013b); and open downwards triangles: Valeev et al. (2013). Only data sets containing V band data were used in these plots. Only errors larger than 0.3 mag are shown.

with its corresponding light curves, show variations that indicate an S Dor variability.

Several measurements were reported during the tracing of the current changes in the light curve of Var C. This shows that even though Var C is a long known LBV, it is still necessary and important to trace its behaviour further in order to fully understand the various features of LBVs.

As recently shown for the LBV R71 in the LMC (Walborn et al. 2014), only by compiling a light curve over ~ 100 years is it possible to detect photometric variation on long timescales. These features’ (as in the case of R71) two broad maxima at 1914 and 1939 give rise to physical events in the star, which are currently unknown and far from being understood. The brightness of R71 has increased during the last five years and reached the highest maximum ever reported (Walborn et al. 2014). In addition, the R71 photometric behaviour seems like what we found for Var C. Indications of regular change between

bright and dim peaks with similar maxima and minima (in magnitudes) are visible in R71, as for Var C. R71 shows broad and overlaid narrow maxima that appear to have some (but not necessarily strict) periodicity, similar to the structures in the light curve of Var C that we report in this paper. Also, an overlaid secular trend towards higher luminosity seems to be present, again very similar to the one in Var C.

Another feature of the R71 light curve is the trend toward the duration of the maxima being shorter with increasing amplitudes (Walborn et al. 2014). This may also be present in the light curve of Var C. It also may explain the rather small amplitude of the 1905 maximum of Var C indicated in our light curve. The increasing time interval between outbursts of R71 (Walborn et al. 2014) does not appear to be present in the light curve of Var C. Therefore, Var C may not (yet) be in an evolutionary phase of accelerated changes (e.g. Moriya et al. 2014). This is also supported by the absence of Ca II emission lines (and

therefore a dense envelope), as reported for R71 (Bonanos et al. (2009), Gamen et al. (2012), Mehner et al. (2013)). The historic light curve of R71 appears to be rather more strongly modulated than that of Var C, and especially the recent outburst of R71 (Gamen et al. (2012), Mehner et al. (2013)) is much more extreme than the one of Var C (Humphreys et al. 2013a).

Based on the similarity to R71, one may speculate that the semi-periodicity plus the secular brightening trend in the light curve of Var C is an indication that the evolutionary state of both stars is going to change, and the current, rather unexpected brightening of Var C is an indication of a coming large eruption as in R71. If this should happen to Var C soon, it would give rise to a new phenomenon in LBVs: large eruptions following L-S Dor variability are overlayed on a secular brightening trend on timescales of 100 years and may be linked to accelerated evolution towards a supernova. A monitoring of the subsequent development of the current bright state of Var C is therefore much needed. Clearly, a hunt for more historic plates will be very fruitful.

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References

- Afanasiev, V. L. & Moiseev, A. V. 2005, *Astronomy Letters*, 31, 194
- Bertin, E. & Arnouts, S. 1996, *A&AS*, 117, 393
- Bonanos, A. Z., Massa, D. L., Sewilo, M., et al. 2009, *AJ*, 138, 1003
- Brunzendorf, J. & Meusinger, H. 1999, *A&AS*, 139, 141
- Burggraf, B., Weis, K., Bomans, D. J., & Henze, M. 2011, *Bulletin de la Societe Royale des Sciences de Liege*, 80, 356
- Clark, J. S., Castro, N., Garcia, M., et al. 2012, *A&A*, 541, A146
- Conti, P. S. 1984, in *IAU Symposium*, Vol. 105, *Observational Tests of the Stellar Evolution Theory*, ed. A. Maeder & A. Renzini, 233
- Demleitner, M., Accomazzi, A., Eichhorn, G., et al. 2001, in *Astronomical Society of the Pacific Conference Series*, Vol. 238, *Astronomical Data Analysis Software and Systems X*, ed. F. R. Harnden, Jr., F. A. Primini, & H. E. Payne, 321
- Dolphin, A. E. 2000, *PASP*, 112, 1383
- Fabrika, S. & Sholukhova, O. 1995, *Ap&SS*, 226, 229
- Gamen, R., Walborn, N., Morrell, N., Barba, R., & Fernandez Lajus, E. 2012, *Central Bureau Electronic Telegrams*, 3192, 1
- Henze, M., Meusinger, H., & Pietsch, W. 2008, *A&A*, 477, 67
- Hubble, E. & Sandage, A. 1953, *ApJ*, 118, 353
- Humphreys, R. M. 1975, *ApJ*, 200, 426
- Humphreys, R. M. 1978, *ApJ*, 219, 445
- Humphreys, R. M., Blaha, C., D’Odorico, S., Gull, T. R., & Benvenuti, P. 1984, *ApJ*, 278, 124
- Humphreys, R. M. & Davidson, K. 1994, *PASP*, 106, 1025
- Humphreys, R. M., Davidson, K., Gordon, M. S., et al. 2014, *ApJ*, 782, L21
- Humphreys, R. M., Davidson, K., Grammer, S., et al. 2013a, *ApJ*, 773, 46
- Humphreys, R. M., Leitherer, C., Stahl, O., Wolf, B., & Zickgraf, F.-J. 1988, *A&A*, 203, 306
- Humphreys, R. M. & Warner, J. W. 1978, *ApJ*, 221, L73
- Humphreys, R. M., Weis, K., Burggraf, B., et al. 2013b, *The Astronomer’s Telegram*, 5362, 1
- Ivanov, G. R., Freedman, W. L., & Madore, B. F. 1993, *ApJS*, 89, 85
- Jaschek, C. & Jaschek, M. 1987, *The classification of stars*, ed. M. Jaschek, C. & Jaschek
- Kaluzny, J., Stanek, K. Z., Krockenberger, M., et al. 1998, *AJ*, 115, 1016
- Kenyon, S. J. & Gallagher, III, J. S. 1985, *ApJ*, 290, 542
- Koenigsberger, G., Georgiev, L., Hillier, D. J., et al. 2010, *AJ*, 139, 2600
- Kurtev, R. G., Corral, L. J., & Georgiev, L. 1999, *A&A*, 349, 796
- Lenz, P. & Breger, M. 2005, *Communications in Asteroseismology*, 146, 53
- Lovas, M. & Zsoldos, E. 1988, *Information Bulletin on Variable Stars*, 3193, 1
- Macri, L. M., Stanek, K. Z., Sasselov, D. D., Krockenberger, M., & Kaluzny, J. 2001, *AJ*, 121, 870
- Maeder, A. 1983, *A&A*, 120, 113
- Massey, P., Armandroff, T. E., Pyke, R., Patel, K., & Wilson, C. D. 1995, *AJ*, 110, 2715
- Massey, P., Bianchi, L., Hutchings, J. B., & Stecher, T. P. 1996, *ApJ*, 469, 629
- Massey, P., Hodge, P. W., Holmes, S., et al. 2001, *Bulletin of the American Astronomical Society*, 33, 1496
- Massey, P., Hodge, P. W., Holmes, S., et al. 2002, *Bulletin of the American Astronomical Society*, 34, 1272
- Massey, P., McNeill, R. T., Olsen, K. A. G., et al. 2007, *AJ*, 134, 2474
- Massey, P., Olsen, K. A. G., Hodge, P. W., et al. 2006, *AJ*, 131, 2478
- Mehner, A., Baae, D., Rivinius, T., et al. 2013, in *Massive Stars: From alpha to Omega*, 168
- Meusinger, H., Henze, M., Birkle, K., et al. 2010, *A&A*, 512, A1
- Meynet, G. & Maeder, A. 2005, *A&A*, 429, 581
- Mighell, K. J. 1998, *CCDCAP: CCD Circular Aperture Photometry*
- Mochejska, B. J., Kaluzny, J., Stanek, K. Z., Sasselov, D. D., & Szentgyorgyi, A. H. 2001, *AJ*, 122, 2477
- Moriya, T. J., Maeda, K., Taddia, F., et al. 2014, *MNRAS*, 439, 2917
- Nijland, A. A. 1901, *Astronomische Nachrichten*, 154, 413
- Parker, J. W. & Garmany, C. D. 1993, *AJ*, 106, 1471
- Pellerin, A. & Macri, L. M. 2011, *ApJS*, 193, 26
- Rosino, L. & Bianchini, A. 1973, *A&A*, 22, 453
- Scowcroft, V., Bersier, D., Mould, J. R., & Wood, P. R. 2009, *MNRAS*, 396, 1287
- Sharov, A. S. 1973, *Peremennye Zvezdy*, 19, 3
- Sharov, A. S. 1990, *Soviet Astronomy*, 34, 364
- Sharov, A. S., Esipov, V. F., & Lyutyi, V. M. 1975, *Soviet Astronomy Letters*, 1, 30
- Shemmer, O., Leibowitz, E. M., & Szkody, P. 2000, *MNRAS*, 311, 698
- Sholukhova, O., Abolmasov, P., Fabrika, S., & Afanasiev, V. 2007, 361, 491
- Sholukhova, O., Fabrika, S., Roth, M., & Becker, T. 2004, *Baltic Astronomy*, 13, 156
- Shporer, A. & Mazeh, T. 2006, *MNRAS*, 370, 1429
- Spiller, F. O. 1992, PhD thesis, Universität Heidelberg
- Szeifert, T., Humphreys, R. M., Davidson, K., et al. 1996, *A&A*, 314, 131
- Valeev, A., Fabrika, S., & Sholukhova, O. 2013, *The Astronomer’s Telegram*, 5538, 1
- van den Bergh, S., Herbst, E., & Kowal, C. T. 1975, *ApJS*, 29, 303
- van Genderen, A. M. 2001, *A&A*, 366, 508
- van Genderen, A. M., Sterken, C., & de Groot, M. 1997, *A&A*, 318, 81
- Viotti, R., Rossi, C., Montagni, F., & Gualandri, R. 2013, *The Astronomer’s Telegram*, 5403, 1
- Viotti, R. F., Rossi, C., Polcaro, V. F., et al. 2006, *A&A*, 458, 225
- Walborn, N. R., Gamen, R. C., Barba, R. H., & Morrell, N. I. 2014, *The Astronomer’s Telegram*, 6295, 1
- Weaver, R., McCray, R., Castor, J., Shapiro, P., & Moore, R. 1977, *ApJ*, 218, 377
- Weis, K. 2011, *Bulletin de la Societe Royale des Sciences de Liege*, 80, 440
- Weis, K. & Bomans, D. J. 2005, *A&A*, 429, L13
- Wilson, C. D. 1991, *AJ*, 101, 1663
- Zharova, A. & Sholukhova, O. 2004, *Communications in Asteroseismology*, 145, 28

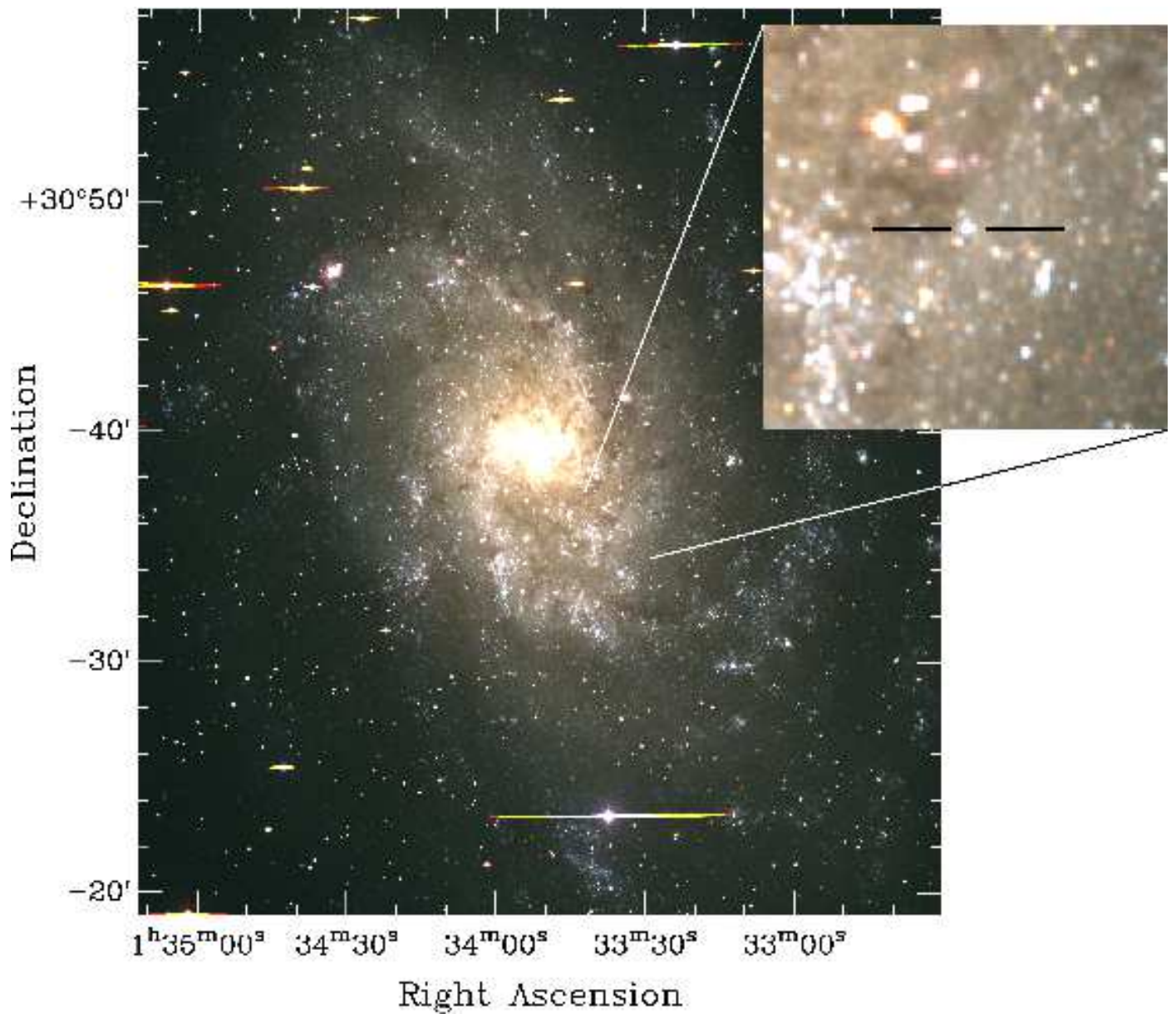


Fig. 1. RGB-image of M33 and Var C. The colour image was generated from the R, V, and B band images from the Thüringer Landessternwarte (TLS) Tautenburg taken 6 January 2008. North is up and east to the left.

Table 2. Summary of optical spectra of Var C.

Date	JD	Features	Spectral Type	Ref.
30 Nov. 1946	2432155	Ca II K and Ca II H in absorption with nearly equal strength	later than F0	1
23 Aug. 1947	2432421	H γ and H δ weakly in absorption Ca II K and Ca II H in absorption with nearly equal strength	later than F0	1
24/25 July – 22 Sept. 1949	2433122 – 2433182	faint H β in emission		1
3 Aug. – 28/31 Oct. 1951	2433862 – 2433951	H β and H γ in emission Ca II K and Ca II H in absorption	late A-type ^a	1
29 Nov. 1951	2433980	H β and H γ in emission		1
27/28 Sept. 1973	2441953	bright H α in emission		2
14 Oct. – 10 Nov. 1974	2442335 – 2442362	several hydrogen, He I Fe II, and [Fe II] lines in emission Ca II K in absorption	late B-type ^a	3
Aug. 1976	≈2443006	compared to previous spectrum: hydrogen and He I emission lines weaker some of the Fe II and [Fe II] lines no longer seen	early B-type ^a	4
10/11 Nov. 1983	2445649.5	H α , H γ , and numerous Fe II lines in emission all with P-Cygni profiles strong Mg II λ 4481 in absorption	A-type ^a	5
Nov. – Dec. 1985	≈2446385 – ≈2446415	H α and H β in emission several strong Fe II and ionised metal lines in absorption I(Ca II K) > I(Ca II H + H ϵ)	F0Ia–F5Ia	6
Aug. – Sept. 1986	≈2446658 – ≈2446689	weaker metallic lines I(Ca II H + H ϵ) > I(Ca II K)	A2–A3	6
15/16/17 Sept. 1987	2447054 – 2447056	Fe II and other metallic lines in absorption several Fe II-lines in emission H α , H β , and H γ showed P-Cygni profiles	A-type	6
3/6 Oct. – 13 Dec. 1992	2448899 – 2448970	weak He I lines in absorption compared to previous spectra: hydrogen and Fe II emission lines getting stronger	late B-type ^a	7
14/15 Dec. 1993	2449336.5	pronounced hydrogen lines in emission several Fe II and [Fe II] lines in emission weak He I line	late B-type ^a	8
30 Nov. 2003	2452974	H β in emission and numerous metallic lines in absorption	F0Ia–F5Ia	9
13 Nov. 2004	2453323	H α , H β , and H γ in emission, some weak Fe I lines in absorption or emission	A-type	10
7/8 Dec. 2004 – 16 Jan. 2005	2453347 – 2453387	strong hydrogen lines in emission several Fe II and [Fe II] lines in emission	B[e]	11
22 Oct. 2008	2454762	H α and H β , in emission, some He I lines and several Fe I lines in emission	B-type	10
29 Sept. – 2 Oct. 2010	2455469 – 2455472	H α , H β , and H γ in emission, several He I and Fe II lines in emission, P-Cygni profiles	B-type ^a	9
3 Oct. 2010	2455473	hydrogen, He I, Fe II, and [Fe II] lines in emission, P-Cygni profiles	B1–B2	12
18 Sept. 2013	2456554	hydrogen lines in emission	A-type ^a	13
5 Oct. 2013	2456571	Fe II, [Fe II], and strong hydrogen lines in emission, P-Cygni profiles	late B-type ^a	14
7 Oct. 2013	2456573	He I very weakly in absorption hydrogen in emission (weaker than in 10/2010), Ca II and Mg II in absorption, Fe II in emission with P-Cygni profiles	late A-type	12
1/2 Nov. 2013	2456598.5	Fe II, [Fe II], and strong hydrogen lines in emission, P-Cygni profiles He I very weakly in absorption	late B-type ^a	14

Notes. ^(a) estimated spectral type based upon the description of the spectrum

References. (1) Hubble & Sandage (1953); (2) Sharov et al. (1975); (3) Humphreys (1975); (4) Humphreys (1978); (5) Kenyon & Gallagher (1985); (6) Humphreys et al. (1988); (7) Szeifert et al. (1996); (8) Massey et al. (1995); (9) Clark et al. (2012); (10) this paper; (11) Viotti et al. (2006); (12) Humphreys et al. (2014); (13) Viotti et al. (2013); (14) Valeev et al. (2013)

Table 3. Light curve data from the literature.

JD	m_{pg}	B	B_{err}	Reference
2414910	17.1	17.2		Hubble & Sandage (1953)
2416131	16.7	16.8		"
2418969	17.3	17.4		"
2420716	17.7	17.8		"
2422503	17.3	17.4		"
2422865	17.5	17.6		"
2423248	17.4	17.5		"
2423975	17.4	17.5		"
2424333	17.4	17.5		"
2424694	17.3	17.4		"
2425056	17.5	17.6		"
2425414	17.6	17.7		"
2425776	17.2	17.3		"
2426152	17.4	17.5		"
2426528	17.5	17.6		"
2426886	17.3	17.4		"
2427620	17.4	17.5		"
2427989	17.5	17.6		"
2428340	17.3	17.4		"
2428712	17.2	17.3		"
2429077	17.2	17.3		"
2429446	16.3	16.4		"
2429808	16.6	16.7		"
2431729	15.6	15.7		"
2432039	15.3	15.4		"
2432039	15.2	15.3		"
2432102	15.4	15.5		"
2432171	15.4	15.5		"
2432379	15.5	15.6		"
2432390	15.3	15.4		"
2432437	15.5	15.6		"
2432437	15.3	15.4		"
2432583	15.3	15.4		"
2432814	15.5	15.6		"
2432887	15.3	15.4		"
2433548	15.6	15.7		"
2433617	15.9	16.0		"
2433648	16.2	16.3		"
2433975	16.5	16.6		"
2433993	16.4	16.5		"
2434015	16.6	16.7		"
2434184	16.9	17.0		"
2434227	17.0	17.1		"
2434290	16.8	16.9		"
2434379	16.8	16.9		"
2434410	17.1	17.2		"
2434443	16.9	17.0		"
2428807	16.8	16.9		Sharov (1973)
2428814	16.6	16.7		"
2429230	16.6	16.7		"
2429250	16.6	16.7		"
2433891	16.6	16.7		"
2433895	16.4	16.5		"
2434330	16.8	16.9		"
2435394	16.5	16.6		"
2435431	16.7	16.8		"
2436078	16.4	16.5		"
2436821	16.8	16.9		"
2437547	16.5	16.6		"
2437911	16.7	16.8		"
2437932	16.6	16.7		Sharov (1973)
2437948	16.6	16.7		"
2437963	16.6	16.7		"
2438016	16.5	16.6		"
2438292	16.4	16.5		"
2439036	16.6	16.7		"
2439418	16.20	16.30		"

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2439421	16.35	16.45		"
2441217	16.7	16.8		"
2441566	17.00	17.10		"
2441570	16.80	16.90		"
2441579	16.77	16.87		"
2437212	17.0	17.1		Rosino & Bianchini (1973)
2437237	17.1	17.2		"
2437245	17.1	17.2		"
2437289	17.1	17.2		"
2437329	17.1	17.2		"
2437373	17.1	17.2		"
2437529	17.1	17.2		"
2437570	17.0	17.1		"
2437621	17.0	17.1		"
2437916	16.9	17.0		"
2437964	16.7	16.8		"
2437978	16.7	16.8		"
2438004	16.7	16.8		"
2438031	16.7	16.8		"
2438033	16.6	16.7		"
2438618	16.5	16.6		"
2439067	16.5	16.6		"
2439436	16.5	16.6		"
2439523	16.7	16.8		"
2439523	16.6	16.7		"
2440145	16.6	16.7		"
2440178	16.6	16.7		"
2440196	16.4	16.5		"
2440200	16.4	16.5		"
2440203	16.6	16.7		"
2440214	16.4	16.5		"
2440251	16.4	16.5		"
2440506	16.8	16.9		"
2440539	16.7	16.8		"
2440550	16.8	16.9		"
2440576	16.8	16.9		"
2440831	16.9	17.0		"
2440864	16.9	17.0		"
2440889	16.9	17.0		"
2440908	16.8	16.9		"
2440937	16.9	17.0		"
2440955	16.9	17.0		"
2441010	17.0	17.1		"
2441189	16.9	17.0		"
2441225	16.9	17.0		"
2441265	16.9	17.0		"
2441269	16.9	17.0		"
2441309	16.9	17.0		"
2441324	16.9	17.0		"
2441335	17.0	17.1		"
2441536	17.0	17.1		"
2439090.51	16.6	16.7	≈ 0.5	Lovas & Zsoldos (1988)
2439498.38	16.3	16.4	"	"
2439529.30	16.5	16.6	"	"
2439711.55	16.1	16.2	≈ 0.5	Lovas & Zsoldos (1988)
2439766.41	16.4	16.5	"	"
2439796.44	16.5	16.6	"	"
2439827.53	16.7	16.8	"	"
2440073.56	16.4	16.5	"	"
2440092.48	16.1	16.2	"	"
2440144.49	16.6	16.7	"	"
2440157.49	16.1	16.2	"	"
2440183.42	16.5	16.6	"	"
2440203.38	16.4	16.5	"	"
2440230.24	16.4	16.5	"	"
2440654.32	16.6	16.7	"	"
2440798.54	16.6	16.7	"	"

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2440837.56	16.7	16.8	"	"
2440916.47	16.7	16.8	"	"
2441164.53	16.7	16.8	"	"
2441183.50	16.7	16.8	"	"
2441213.45	16.6	16.7	"	"
2441518.55	16.4	16.5	"	"
2441520.51	16.6	16.7	"	"
2441625.46	16.6	16.7	"	"
2441679.26	16.6	16.7	"	"
2441687.38	16.5	16.6	"	"
2441689.28	16.6	16.7	"	"
2441714.34	16.5	16.6	"	"
2441903.53	16.7	16.8	"	"
2441921.55	16.7	16.8	"	"
2442008.55	16.7	16.8	"	"
2442066.40	16.7	16.8	"	"
2442095.30	16.7	16.8	"	"
2442278.44	16.7	16.8	"	"
2442397.36	16.8	16.9	"	"
2442473.31	16.8	16.9	"	"
2442695.46	16.7	16.8	"	"
2442725.47	16.8	16.9	"	"
2442754.44	16.7	16.8	"	"
2442756.50	16.8	16.9	"	"
2443013.52	16.7	16.8	"	"
2443072.49	16.7	16.8	"	"
2443191.30	16.7	16.8	"	"
2443344.57	16.6	16.7	"	"
2443399.43	16.8	16.9	"	"
2443430.50	16.6	16.7	"	"
2443464.50	16.7	16.8	"	"
2443489.29	16.7	16.8	"	"
2443720.55	16.7	16.8	"	"
2443756.43	16.7	16.8	"	"
2443757.56	16.8	16.9	"	"
2443787.54	16.8	16.9	"	"
2443809.56	16.6	16.7	"	"
2443815.28	16.6	16.7	"	"
2444136.58	16.6	16.7	"	"
2444167.47	16.6	16.7	"	"
2444256.30	16.7	16.8	"	"
2444554.47	16.6	16.7	"	"
2444912.59	16.8	16.9	"	"
2444989.29	16.6	16.7	"	"
2445018.31	16.7	16.8	"	"
2445197.53	16.8	16.9	"	"
2445230.43	16.8	16.9	"	"
2445261.46	16.7	16.8	"	"
2445347.26	16.6	16.7	≈ 0.5	Lovas & Zsoldos (1988)
2445593.50	16.0	16.1	"	"
2445615.46	16.0	16.1	"	"
2445647.49	15.6	15.7	"	"
2445940.56	15.5	15.6	"	"
2446026.43	15.4	15.5	"	"
2446030.28	15.3	15.4	"	"
2446321.43	15.4	15.5	"	"
2446355.55	15.6	15.7	"	"
2446441.35	15.3	15.4	"	"
2446468.36	15.3	15.4	"	"
2446677.57	15.4	15.5	"	"
2446706.41	15.5	15.6	"	"
2446738.50	15.7	15.8	"	"
2446763.46	15.6	15.7	"	"
2447060.48	15.5	15.6	"	"
2439502.71		17.77	≈ 0.7	van den Bergh et al. (1975)
2439679.95		17.58	"	"
2440209.73		17.38	"	"

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2440212.62		17.87	''	''
2440212.68		17.40	''	''
2440476.79		17.76	''	''
2440476.86		17.60	''	''
2440479.76		17.65	''	''
2440858.75		18.10	''	''
2440863.69		18.10	''	''
2441245.86		17.95	''	''
2441508.94		17.89	''	''
2441512.92		16.92	''	''
2441513.93		17.44	''	''
2441514.85		17.52	''	''
2441981.84		17.68	''	''
2442363.72		17.68	''	''
2442364.60		17.63	''	''
2442365.63		17.40	''	''
2442366.74		17.04	''	''
2441572	16.71	16.81		Sharov (1990)
2441926	16.74	16.84		''
2441956	16.78	16.88		''
2441975	16.77	16.87		''
2442316	16.77	16.87		''
2442333	16.63	16.73		''
2442364	17.32	17.42		''
2442639	17.36	17.46		''
2442659	17.30	17.40		''
2442692	17.08	17.18		''
2442721	17.06	17.16		''
2443015	17.22	17.32		''
2443400	17.26	17.36		''
2443499	17.50	17.60		''
2443782	17.32	17.42		''
2444108	16.82	16.92		''
2444140	16.92	17.02		''
2444165	16.84	16.94		''
2444461	16.72	16.82		''
2444493	16.85	16.95		''
2444828	16.77	16.87		''
2444853	17.20	17.30		''
2444880	17.12	17.22		''
2445203	17.18	17.28		''
2445234	16.94	17.04		''
2445263	16.91	17.01		Sharov (1990)
2445286	16.84	16.94		''
2445559	16.17	16.27		''
2445588	15.83	15.93		''
2445615	15.87	15.97		''
2445703	15.72	15.82		''
2445920	15.52	15.62		''
2445944	15.50	15.60		''
2445971	15.48	15.58		''
2445994	15.50	15.60		''
2446028	15.54	15.64		''
2446298	15.60	15.70		''
2446326	15.58	15.68		''
2446358	15.48	15.58		''
2446654	15.57	15.67		''
2446684	15.56	15.66		''
2446709	15.51	15.61		''
2446764	15.50	15.60		''
2447034	15.34	15.44		''
2447062	16.05	16.15		''
2447092	16.06	16.16		''
2447124	16.00	16.10		''
2447148	16.12	16.22		''
2447419	16.33	16.43		''
2447449	16.45	16.55		''

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2441900		16.81		Zharova & Sholukhova (2004)
2441930		16.60		"
2441950		16.69		"
2442230		17.11		"
2442280		16.87		"
2442310		17.00		"
2442330		17.31		"
2442370		16.81		"
2442380		17.23		"
2442660		17.10		"
2442680		17.50		"
2442690		16.74		"
2442750		17.02		"
2442750		17.39		"
2442750		16.89		"
2443020		17.15		"
2443370		16.71		"
2443380		17.19		"
2443380		17.01		"
2443740		16.86		"
2443760		17.17		"
2444080		17.39		"
2444110		17.20		"
2444130		16.84		"
2444470		17.22		"
2444480		16.82		"
2444500		17.36		"
2444820		16.99		"
2444880		17.20		"
2445220		17.09		"
2445250		16.90		"
2445250		16.72		"
2445260		16.56		"
2445470		15.91		"
2445530		15.77		"
2445540		15.64		"
2445610		16.05		Zharova & Sholukhova (2004)
2445730		15.91		"
2445940		15.75		"
2445990		15.49		"
2446310		15.84		"
2446360		15.50		"
2446690		15.67		"
2446720		15.59		"
2447080		16.09		"
2447080		16.29		"
2447350		16.51		"
2447450		16.08		"
2447470		16.30		"
2447670		16.75		"
2447800		16.87		"
2447880		16.40		"
2448140		16.85		"
2448180		16.71		"
2448250		16.31		"
2448510		16.39		"
2448520		16.62		"
2448570		16.00		"
2448590		16.08		"
2448640		16.51		"
2448850		15.80		"
2448900		16.46		"
2448900		16.71		"
2448940		16.01		"
2449190		16.52		"
2449200		16.19		"
2449210		16.68		"

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2449250		16.80		"
2449580		16.72		"
2449630		16.31		"
2449680		16.20		"
2449690		16.44		"
2449980		16.77		"
2450040		16.46		"
2450090		16.62		"
2450290		16.15		"
2450340		16.47		"
2450370		15.91		"
2450380		16.02		"
2450440		16.18		"
2450610		16.64		"
2450670		16.81		"
2450670		16.31		"
2451020		16.86		"
2451090		16.42		"
2451380		17.01		"
2451430		16.59		"
2451510		16.87		"
2451530		16.71		"
2451750		16.45		"
2451790		16.83		"
2451800		16.62		"
2451820		16.31		"
2452140		16.10		"
2452200		16.56		"
2452250		16.40		"
2452480		16.20		"
2452520		15.97		Zharova & Sholukhova (2004)
2452550		15.76		"
2452600		15.59		"
2452610		15.45		"
2443044		17.12	0.01	Humphreys (1978)
2443428		16.98	0.01	Humphreys & Warner (1978)
2444559±15		17.20	0.01	Humphreys et al. (1984)
2444954±15		17.33	0.01	"
2445197±15		17.24	0.01	"
2445258±15		16.57	0.03	"
2446750±15		16.12	0.03	Humphreys et al. (1988)
2447054±15		16.12	0.08	"
2445286		17.47	0.15	Kurtev et al. (1999)
2445295		17.43	0.15	"
2445296		17.32	0.23	"
2445297		17.39	0.25	"
2445588		15.74	0.23	"
2445588		16.04	0.31	"
2445590		15.94	0.20	"
2445591		15.69	0.16	"
2445623		15.72	0.23	"
2445625		15.90	0.16	"
2445702		15.60	0.08	"
2445929		15.55	0.08	"
2445968		15.41	0.09	"
2446435		15.47	0.08	"
2446707		15.64	0.16	"
2446707		15.46	0.16	"
2446708		15.51	0.07	"
2446708		15.40	0.10	"
2446709		15.58	0.08	"
2446738		15.66	0.11	"
2446738		15.40	0.17	"
2448177		16.36	0.18	"
2448180		16.22	0.17	"
2448180		16.22	0.13	"
2448180		16.42	0.12	"

Table 3. Continued.

JD	m_{pg}	B	B_{err}	Reference
2446703±2		16.43		Massey et al. (1995)
2447416±33		16.51	0.02	Wilson (1991)
2448867		16.29	0.02–0.10	Szeifert et al. (1996)
2448871		16.27	”	”
2448892		16.33	”	”
2448973		16.59	”	”
2448979		16.48	”	”
2449008		16.39	”	”
2451452.7982		17.179	0.001	Mochejska et al. (2001)
2451452.9166		17.188	0.001	”
2451454.6968		17.201	0.001	”
2451454.7299		17.198	0.001	”
2451454.8004		17.189	0.002	”
2451454.8698		17.194	0.002	”
2451454.8784		17.197	0.002	”
2451454.9880		17.208	0.001	”
2451455.7628		17.188	0.002	”
2451455.8708		17.200	0.002	”
2451456.6809		17.218	0.002	”
2451456.7014		17.208	0.001	”
2451456.7246		17.214	0.001	”
2451456.7484		17.228	0.003	”
2451456.7666		17.231	0.003	”
2451456.7939		17.224	0.002	”
2451456.8207		17.213	0.002	Mochejska et al. (2001)
2451456.8403		17.202	0.001	”
2451457.6993		17.187	0.002	”
2451457.8141		17.209	0.002	”
2451457.8759		17.202	0.001	”
2451457.9503		17.215	0.002	”
2451484.6991		17.181	0.001	”
2451484.7858		17.177	0.001	”
2451484.8954		17.166	0.001	”
2451486.6341		17.181	0.002	”
2451486.7428		17.185	0.001	”
2451488.6521		17.160	0.001	”
2451488.7601		17.185	0.001	”
2451488.7806		17.178	0.001	”
2453347		16.5	0.2	Viotti et al. (2006)
2453641		16.6	0.1	”
2456536.78		15.87		Humphreys et al. (2013b)
2456598		15.9		Valeev et al. (2013)

Table 4. Light curve data.

JD	B	B _{err}	V	V _{err}	Observatory
2421573	17.0	0.4			HDAP
2421573	17.3	0.4			"
2417797	17.5	0.1			"
2417800	17.2	0.2			"
2418149	17.3	0.2			"
2421580	17.5	0.1			"
2421580	17.4	0.1			"
2421624	17.5	0.1			"
2421624	17.5				"
2422552	16.9	0.4			"
2422552	17.3	0.1			"
2423342	17.1				"
2423353	17.1	0.1			"
2438266.55			16.3	0.2	TLS plates
2438268.49	16.7	0.2	16.4	0.2	"
2438286.52	15.8	0.2	16.1	0.2	"
2438287.49	15.9	0.4	15.0	0.3	"
2438289.51	16.3	0.3	16.2	0.1	"
2440500.46			16.1	0.1	"
2440501.54			16.4	0.1	"
2440503.52			16.6	0.1	"
2440504.57			16.4		"
2440506.43			16.0	0.2	"
2440508.50	16.8	0.2			"
2442805.29	16.9	0.2			"
2443816.33	16.8	0.2			"
2444194.44	17.2	0.2			"
2444222.40	17.2	0.2			"
2444253.31	16.1	0.4			"
2444489.56	16.9	0.2			"
2444490.54	16.8	0.3			"
2444491.57	17.2	0.2			"
2444523.37	16.9	0.2			"
2444500.58	16.8	0.3			"
2444544.36	17.4	0.2			"
2444545.34	17.3	0.3			"
2444912.39	16.8	0.3			"
2444912.42	16.5	0.3			"
2444912.46	16.5	0.3			"
2444912.48	16.7	0.3			"
2444933.41	17.1	0.2			"
2444933.44	17.1	0.2			"
2444933.46	16.9	0.2			"
2444967.34	17.0	0.2			"
2444967.35	17.2	0.2			"
2444967.37	17.1	0.2			"
2444967.38	17.0	0.2			"
2444967.39	16.9	0.2			"
2444988.36	16.8	0.2			"
2444988.37	17.0	0.2			"
2444988.38	16.9	0.2			"
2444989.32	16.9	0.3			"
2444989.34	17.0	0.3			"
2445020.28	17.0	0.2			"
2445370.25	16.3	0.2			"
2445370.27	16.3	0.2			"
2445370.30	16.3	0.2			"
2445372.30	16.3	0.2			"
2446320.58	15.7	0.3			"
2446321.62	16.5	0.2			"
2446650.56	16.0	0.2			TLS plates
2446678.55	17.0	0.2			"
2446678.58	17.0	0.2			"
2446678.60	17.0	0.2			"
2446683.52	16.1	0.2			"
2446683.55	16.1	0.2			"
2446683.58	16.2	0.2			"

Table 4. Continued.

JD	B	B _{err}	V	V _{err}	Observatory
2446714.60	15.9	0.2			"
2446714.62	15.7	0.2			"
2446716.54	16.0	0.2			"
2446716.57	16.0	0.2			"
2446731.37	16.4	0.2			"
2446731.42	16.1	0.2			"
2446737.46	16.3	0.2			"
2446737.59	16.1	0.2			"
2446742.44	16.7	0.2			"
2446762.38	16.0	0.3			"
2446763.30	16.5	0.3			"
2446764.43	16.3	0.2			"
2446765.46	16.1	0.2			"
2447039.50	16.1	0.1			"
2447042.62	15.8	0.1			"
2447775.49	16.7	0.1			"
2447776.48	16.7	0.1			"
2447777.47	16.1	0.1			"
2447823.34	16.4	0.2			"
2447823.36	16.6	0.1			"
2447825.37	16.8	0.1			"
2447827.34	16.5	0.2			"
2448893.53	16.4				"
2448927.52	16.4	0.2			"
2448928.53	16.3	0.1			"
2448950.50	16.3	0.1			"
2449658.44	16.7	0.1			"
2450048.40	16.6	0.2			"
2450432.39	16.2	0.2			"
2450332.85	17.31	0.03			DIRECT
2450334.90	16.99	0.34			"
2450365.80	17.25	0.01			"
2450688.97	17.84	0.01			"
2450690.96	17.79	0.01			"
2450691.93	17.68	0.01			"
2450694.87	17.62	0.01			"
2450694.99	17.75	0.01			"
2450695.93	17.62	0.01			"
2450695.94	17.03	0.05			"
2450696.92	17.72	0.02			"
2450696.99	17.81	0.01			"
2450730.93	17.80	0.01			"
2451044.85			17.18	0.17	"
2451051.95	17.80	0.04	17.00	0.18	"
2451055.86			17.96	0.07	"
2451056.99			17.95	0.33	"
2451057.88			17.26	0.17	"
2451074.93			17.91	0.18	"
2451101.89			18.37	0.16	"
2451102.81			18.15	0.18	"
2451103.82			18.18	0.12	"
2451104.85			16.05	0.15	"
2451105.96			16.12	0.14	"
2451106.70			16.88	0.15	"
2451138.75	18.04	0.01	17.97	0.18	DIRECT
2451139.88			16.39	0.35	"
2451140.77			17.65	0.21	"
2451141.76			16.55	0.16	"
2451142.87			17.34	0.18	"
2451143.80			18.42	0.11	"
2451821.4	16.65	0.01	16.53	0.01	NOAO
2452170.3	16.45	0.01	16.33	0.01	"
2452499.91	17.03	0.07	15.85	0.03	WIYN
2452499.95	16.22	0.19	15.93	0.09	"
2452517.79	16.79	0.13	15.78	0.06	"
2452517.80	16.64	0.09	15.74	0.04	"
2452531.74	17.12	0.15	15.82	0.07	"

Table 4. Continued.

JD	B	B _{err}	V	V _{err}	Observatory
2452531.78	16.75	0.05	15.93	0.09	"
2452557.79	16.03	0.16	15.73	0.08	"
2452557.80	16.82	0.16	15.98	0.13	"
2452589.80	16.03	0.17	15.83	0.08	"
2452589.80	16.51	0.12	15.85	0.10	"
2452646.63	17.09	0.13	15.87	0.08	"
2452646.64	16.76	0.08	15.80	0.06	"
2452662.60	18.05	0.70	15.83	0.07	"
2452662.61	16.32	0.09	15.75	0.06	"
2452901.76	17.02	0.21	15.76	0.03	"
2452901.77	16.61	0.23	15.99	0.11	"
2452908.80	16.09	0.12	15.85	0.05	"
2452908.81	16.33	0.08	15.87	0.06	"
2452932.80	16.48	0.02	15.54	0.01	"
2452932.80	16.52	0.01	15.58	0.02	"
2452958.81	16.10	0.10	15.95	0.08	"
2452958.82	16.58	0.06	15.80	0.06	"
2453000.65	16.80	0.06	15.73	0.03	"
2453000.65			15.75	0.03	"
2453567.95	16.93	0.16	16.24	0.06	"
2453567.95	16.87	0.14	16.29	0.09	"
2453764.3	16.80	0.01			TLS CCD
2454387.5	17.02	0.02	16.94	0.01	"
2454472.3	17.17	0.01	17.08	0.01	"
2454742.3	17.15	0.02	17.07	0.01	"
2454823	17.20	0.02			"
2454852	17.19	0.02	17.10	0.02	"
2454891	17.25	0.04	17.20	0.02	"
2455094.5	17.56	0.01			"
2455124.4	17.56	0.02			"
2455125.6	17.54	0.02	17.48	0.01	"
2455126.6	17.53	0.02	17.47	0.01	"
2455248.3	17.53	0.02	17.51	0.01	"
2455621.0	16.40	0.02	16.21	0.02	"
2455806.1	16.13	0.01	15.81	0.01	"
2455834.5	15.98	0.01	15.79	0.01	"
2455835.5	16.07	0.01	15.79	0.01	"
2455838.4	16.05	0.07	15.84	0.04	"
2453943.6	17.03	0.01			CAHA
2453983.6	16.84	<0.01			"
2454031.3	16.55	<0.01			"
2454376.4652			16.87		COoSAI
2454376.4689			16.88		"
2454376.4719			16.85		"
2454376.4748			16.91		"
2454376.4777			16.86		"
2454376.4806			16.88		"
2454376.4864			16.88		"
2454376.4893			16.91		COoSAI
2454376.4923			16.88		"
2454376.4952			16.90		"
2454376.4981			16.90		"
2454376.5010			16.86		"
2454376.5068			16.83		"
2454376.5137	16.96				"
2454376.5197	17.02				"
2454385.4800			16.86		"
2454385.4825			16.81		"
2454385.4838	17.00				"
2454389.4070			16.87		"
2454389.4102			16.85		"
2454389.4110			16.81		"
2454389.4118			16.85		"
2454389.4131	17.03				"
2454389.4146	16.99				"
2454389.4161	16.96				"
2454391.4144			16.89		"

Table 4. Continued.

JD	B	B _{err}	V	V _{err}	Observatory
2454391.4152			16.86		"
2454391.4160			16.85		"
2454391.4173	16.20				"
2454391.4188	16.29				"
2454391.4203	16.23				"
2455141.4706	17.18				"
2455141.4724			16.33		"
2455144.3362	17.19				"
2455144.3378			17.30		"
2455144.3394	17.23				"
2455144.3410			17.37		"
2455144.3426	17.32				"
2455144.3442			17.34		"
2455144.3458	17.29				"
2455144.3474			17.36		"
2455144.3490	17.26				"
2455144.3506			17.37		"
2455144.3522	17.24				"
2455144.3538			17.41		"
2455144.3570			17.33		"
2455144.3586	17.24				"
2455144.3602			17.41		"
2455144.3618	17.40				"
2455144.3634			17.54		"
2456139.89			15.64		John Martin (priv. com.)
2456209.65			15.85		"
2456274.61			15.86		"